The Biomechanics of Dragon Boat Paddling

By

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Abstract

In dragon boat racing, boat speed is generated by paddle propulsion produced by human movement. However at the fundamental level it is the interaction of the paddle with water that produces the forces generating boat speed. Literature on the biomechanics of paddle propulsion is sparse and is concerned predominantly with human movement and not with the fundamentals of paddling. This thesis examines the biomechanics of dragon boat paddling from the perspective of the paddle. Kinetic and kinematic paddle data were collected sequentially for each test participant from two dragon boat crews via 30 s maximum effort paddling tests. A custom built strain-gauged paddle sampled the paddling forces at 200 Hz whilst a stationary video camera (Sony HDR-HC7) recorded a single representative racing paced paddling stroke at 200 Hz. A light flash recorded by the video camera and its trigger signal recorded by the force data collection system ensured synchronisation. Excel spreadsheets converted the data into kinetic and kinematic paddle parameters for each study.

Study one operationalised a qualitative coaching model for teaching paddlers a good dragon boat paddling stroke and produced strong support for the coaching model via a statistical comparison of more skilled paddlers with paddlers less skilled. *More skilled paddlers produced significant superior results for paddle reach at water contact, rate of force development on water entry, maximum paddle force, drive impulse and drive impulse rate, force rate reduction at paddle exit and paddle impulse during recovery.*

Study two investigated the kinetic, kinematic and temporal paddle parameters that differentiate a more successful dragon boat racing crew from a less successful crew. *The more successful racing crew produced significant superior results for rate of force development during water entry, average drive force, average peak to drive force ratio, rate of force reduction at paddle exit, paddle reach at water contact, paddle angle at maximum* *force, average paddle angular velocity in water, paddle displacement on the water surface, the stroke length, and the time duration of the catch and the paddling stroke.*

Study three examined the kinetic and temporal paddle parameters that differentiate more skilled paddlers from the less skilled. *More skilled paddlers produced significant superior results for the rate of force development during paddle entry, maximum paddle force, paddle force at vertical position, average force during the catch and drive phases of the paddling stroke, average peak to drive force ratio, rate of force reduction at paddle exit, drive impulse, drive impulse rate, stroke impulse during recovery. And the time duration of the catch and drive phases of the addling stroke.*

Study four, the final study, established the kinematic paddle parameters that differentiate more skilled paddlers from paddlers less skilled. *The more skilled paddlers produced significant superior results for paddle reach at water contact, average paddle angular velocity in water, paddle displacement on the water surface and paddle angle at water exit.*

Together these four studies provide a biomechanical foundation for the sport of dragon boat racing. Coaches and paddlers can use the findings of this thesis to improve paddling technique, paddling skill and racing performance.

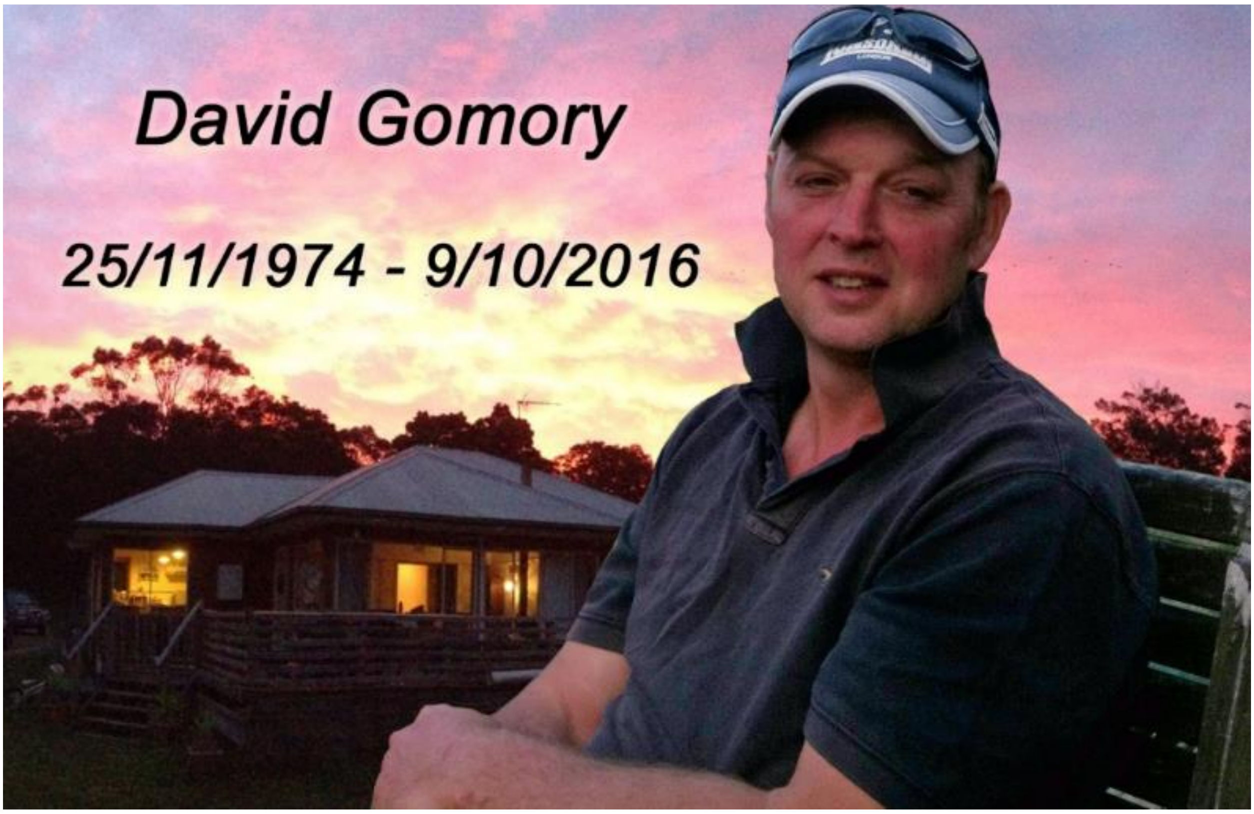
Student declaration

I, Joseph Alexander Gomory, declare that the Master of Applied Science thesis entitled The Biomechanics of Dragon Boat Paddling is no more than 60,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. All work in this thesis was conducted by me.

Signature [redacted] Date July 23, 2018

Dedication

This thesis is dedicated to the memory of my son, much loved and greatly missed.



You were a good person and a good father

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I would like to thank Robert Stokes for developing the electronic data collection system for my strain-gauged paddle that enabled force measurements to be made at 200 Hz. I am also grateful for the support he gave me and the interest he showed in my project over the years.

Robert passed away unexpectedly in 2018. His friendship and expertise is sadly missed.

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I am very appreciative of Simon Taylor my recently appointed co-supervisor for providing a fresh eyes perspective to the draft of my thesis.

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And finally I would like to thank Peta Michael-Gomory for reading my thesis and providing me with a lay person’s perspective.

Peer reviewed published conference publications

Gomory, J., Ball, K. & Stokes (2011). A system to measure the kinematics, kinetics and effort of dragon boat paddling. *Procedia Engineering*, **13**, 457-463. Retrieved from http://www.sciencedirect.com/science/journal/18777058/13

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Chapter 1 – General Introduction

1.1 Modern day dragon boat racing

Modern day dragon boat racing is a highly competitive sport with ties to ancient cultural practices that influence the organisation of events and racing equipment. All regattas begin with the Taoist ceremony of blessing of the boats. The racing equipment is standardised, manufactured under licence, certified and checked at regattas. Technology cannot be used to gain an advantage in racing.

Dragon boat racing is a flat water sport. It uses a single sided paddling technique like canoeing, outrigger and stand-up paddling. Upper body movements resemble that of Olympic flat water canoeing (C1, C2 and C4) whilst lower body movements are similar to that of fixed seat rowing. Teams race in standardised boats using standardised paddles over standardised distances. The sport is governed by the International Dragon Boat Federation (IDBF). Boats and paddles are manufactured by suppliers under a licensing scheme controlled by the IDBF. Currently dragon boat racing is practiced in over 80 countries by men and women of all ages as a social or competitive sport (International Dragon Boat Federation http://www.idbf.org/members, accessed Mar 2, 2018).

Racing is conducted over the standard distances of 200 m, 500 m, 1000 m and 2000 m in gender and age divisions. Open, women and mixed are the gender groupings. Each mixed group consists of equal numbers of men and women. In standard boats the gender mix is ten men and ten women and in small boats it is five men and five women. The age groupings used in dragon boat racing are under 18, under 24, open age, over 40, over 50 and over 60 years of age.

The tools of the sport are the standardised boats and standardised paddles which are checked for compliance at all regattas. For championship events, boats are provided to the competitors by the organisers and all boats are sourced from one manufacturer. Club owned boats cannot be used. Two boat sizes are used in racing; the standard boat (Fig 1.1-1) and the small boat (Fig 1.1-2). Thus there are two separate grades of racing based on boat size. The standard boat seats twenty paddlers in pairs on wooden benches. It is 12.4 m long and 1.16 m wide at its centre with seat spacing's of 0.80 m. The small boat seats ten paddlers in pairs with seat spacing's of 0.875 m. It is 9.0 m long and 1.14 m wide. A sweep (helm or steers person) stands at the rear of the boat, controls the crew via commands and steers the boat with a large sweep oar. A drummer sits on a special seat at the front of the boat drumming in time with the paddling rate of the strokes (the paddlers who sit on the first bench and set the stroke rate of the crew) to encourage team synchronicity.

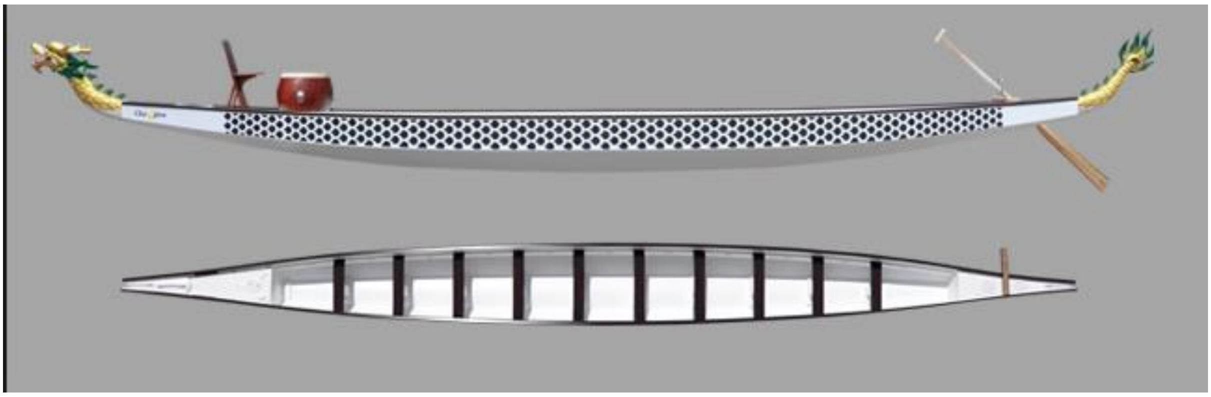

Figure 1.1-1: Illustration of a standard IDBF dragon boat.

Figure 1.1-2: Image of a small IDBF dragon boat.

The paddles used in dragon boat racing are standardised; they all have the same blade size and shape. However the length of the paddle shaft may vary as long as the overall length of the paddle remains within specification (1.05 m to 1.3 m). Paddles may be constructed from different materials. Traditionally paddles were made from wood (Fig 1.1-3) but many paddlers these days prefer carbon fibre due to its lightness (Fig 1.1-4).

Figure 1.1-3: Image of an IDBF dragon boat paddle -wood construction.

Figure 1.1-4: Image of an IDBF dragon boat paddle - carbon fibre construction.

1.2 Racing performance - background information

Countries that are members of the IDBF conduct dragon boat racing at local regattas, state and national championships. Racing at national championships are highly competitive since it is at this level that qualifications for world championships are earned. World championships provide the pinnacle of racing performance. These are held between nations and club crews from IDBF member countries every two years. The World Nations Championships are held in odd numbered years whilst the World Club Crew Championships are held in the even numbered years. Table 1.2-1 shows the winning times for the most recent World Nations Dragon Boat Championships (2017, Kunming, China) for male, female and mixed crews in standard and small boats for the standard race distances. Results for IDBF World Championships are available at https://www.idbf.org/world

Table 1.2-1: Winning times for open age male, female and mixed crews at the International Dragon Boat Federation's 2017 World Nation's Championships in Kunming, China. Note – official race times are reported to 0.001s accuracy.

CREW TYPE	BOAT SIZE	RACE DIST m	CHAMPIONSHIP RACE WINNING TIMES, m:s MEN	WOMEN	MIXED
National	Standard	200	39.655	49.921	45.552
National	Small	200	49.431	56.100	51.479
National	Standard	500	1:52.962	2:09.475	1:58.840
National	Small	500	2:09.123	2:23.074	2:13.351
National	Standard	2000	9:05.691	9:36.479	9:22.304
National	Small	2000	9:52.339	10:38.094	10:16.314

From the above results it can be seen that the average speed for national open age male crews of standard boats range from 5.0 m/s for the 200 m final to 3.7 m/s for the 2000 m. For women the corresponding ranges of speed are 4.0 to 3.5 m/s respectively. The small boats being shorter in length and powered by half the number of paddlers have lower racing speeds. The corresponding ranges of speed for crews of the small boat are 4.1 to 3.4 m/s for men and 3.6 to 3.1 m/s for women.

Just as distance and gender affect performance in terms of attained boat speed so does age. For that reason there are age classifications and races are conducted in age groups. The effect of age can be seen in the winning times of the standard boat races at the most recent World

Nations Dragon Boat Championships (2017, Kunming, China) shown in Table 1.2-2 below. The decline in performance due to age is highest in the sprint events. For example in the 200 m event the winning time for men in the over 60 age category is 30 percent slower than for the open age group. However for the 2000 m races the difference is only 8.3 percent. With regard to gender the differences in performance between men and women are greater in the younger age groups. In the open age 200 m races the wining time for women was 25 percent slower than for men but in the over 60 age group the difference in speed between men and women was only 5.5 percent.

Table 1.2-2: Winning times for the standard age groups (open age, over 40, 50 and 60 years) for male, female and mixed crews at the IDBF 2017 World Nation's Championships. Note – official race times are reported to 0.001s accuracy.

Crew	Boat	Distance	Age	Championship race wining times, m:s		
Type	Size	m	Group	Men	Women	Mixed
National	Standard	200	Open	39.655	49.921	45.552
			Over 40	44.413	52.332	48.581
			Over 50	46.362	54.730	51.398
			Over 60	52.265	55.116	52.765
National	Standard	500	Open	1:52.962	2:09.475	1:58.840
			Over 40	2:00.755	2:12.446	2:07.688
			Over 50	2:02.445	2:17.542	2:11.068
			Over 60	2:12.270	2:16.485	2:11.172
National	Standard	2000	Open	9:05.691	9:36.479	9:22.304
			Over 40	9:17.662	9:59.261	9:30.935
			Over 50	9:19.407	10:13.648	9:43.418
			Over 60	9:50.730	10:42.940	9:54.277

1.3 Paddling technique – an introduction

Due to the foresight of the IDBF in standardising the equipment used, success in dragon boat racing depends on the skill and fitness of the crew and not on technology. A high level of fitness can be achieved by all athletes however fitness alone is not enough to achieve racing success at the highest level of the sport. Skill is needed - fitness is mandatory; an effective, efficient paddling technique is required for racing success.

Boat propulsion is produced by the movements of the paddle through water. These movements generate the driving force and impulse that propel a boat forward. The paddle movements in turn are generated by the body movements of the paddler. Together these actions constitute paddling technique. How effective and efficient the paddling technique is depends on the paddler’s skill.

The terminology used to describe and define the paddling stroke within and between paddle sports and their organisations varies considerably. For example the Fédération Internationale des Sociétés d'Aviron (FISA), the International Rowing Federation, in their coaching manuals describe the rowing stroke as consisting of preparation, entry (catch), drive, finish (extraction or release) and recovery (http://www.worldrowing.com/coaches/). The British Rowing Association uses similar and different terms; beginning (catch), power phase, finish, extraction and recovery to describe the rowing stroke. For the British the term preparation is not defined and the finish and extraction are separate phases (https://www.britishrowing.org/upload/files/CoachingTraining/rowing-glossary.pdf).

In canoeing and kayaking the International Canoe Federation (ICF) coaching manuals (https://www.canoeicf.com/resources) separate the paddling stroke into power (water) and recovery (air) phases to explain paddling technique (ICF level 1 canoe sprint coaching manual p 27). For canoeing the power phase consists of the catch (entry), draw and steering movements of the paddle followed by water exit. Recovery involves the movement of the paddle from exiting the water to the catch position of the next stroke. The paddler relaxes their muscles, breathes in and prepares for the next stroke as the paddle moves to the catch position. This phase of the stroke is called firming. A smooth blending of the phases is essential to achieve good technique. Each phase is important but it is the force, speed and direction of the paddle at the catch that determines boat speed (ICF level 2-3 canoe sprint coaching manual p 66.)

Canoe technical templates describing the paddling stroke exist to assist elite coaches in Canada (http://canoekayak.ca/wp-content/uploads/2014/06/Canoe-Technical-Template.pdf) and the USA (http://boathousedistrict.org/wp-content/uploads/2014/08/Canoe-Technical-Template.pdf). The Canadian template uses the terms set-up, catch, draw, exit and recovery to describe the phases of the paddling stroke. Each phase is a continuous process that blends into the next phase except for the set-up that has a slight pause at the end just before the commencement of the next stroke. The catch, draw and exit are the water phases whilst recovery and set-up are the air phases of the stroke. However there are no clear defining points for the start and finish of each phase in the Canadian template.

For the USA template each phase is also a continuous process and there is a subtle pause at the start of each stroke that occurs between the set-up phase and the drive. There are clear defining points for the start and finish of some phases of the canoe stroke. The terms used to describe the phases of the stroke are set-up, drive, catch, pull, exit and recovery. Set-up is the movement of the athlete into the position from which the paddle is driven to the water. The drive is the period between the end of the set-up and the beginning of the catch. Catch is the phase between water contact and full blade immersion. The pull is between full blade emersion and the start of paddle exit. The exit begins when the pull force declines and concludes when the blade moves clear of the water. Recovery is the air phase that follows the exit.

In dragon boating there are no coaching manuals equivalent to that of FISA and the ICF. The International Dragon Boat Federation (IDBF) does not have any coaching manuals on their website and neither do any of its members. Countries like Australia and Canada conduct courses for dragon boat coaches but these are proprietary and are only available to course attendees. However authors Arlene Chan and Susan Humphries have written a book about dragon boat racing in Canada (Chan & Humphries, 2009) in which some chapters are written by representatives of the Canadian governing body of the sport, Dragon Boats Canada. One such chapter (McDonald & McKenzie, 2009) defines the basic dragon boat paddling technique. The authors of this chapter are also the authors of the coaching manual for Dragon Boats Canada (McDonald & McKenzie, 2008). Thus the information contained in the book chapter can be considered to be authoritative and worth reviewing.

McDonald & McKenzie (2009) maintain that establishing stability and correct seating in the dragon boat is the key to transferring power to the water, creating boat glide and thus boat speed. Correct seating requires correct placement of the feet and buttocks. Paddlers sit against the outboard side of the boat with their outside leg from hip to knee in contact with the boat surface. Both feet are placed on the foot-ribs under the seat in front of the paddler with the heels firmly in contact with the ribs. The outside leg must engage a foot-rib but if allowed by a coach the inside leg can be tucked back. Body weight is distributed and stability is achieved via the three point contact of the outside leg and hip, the buttocks and the heels. This is the standard seating position for a paddling stroke.

The top hand (inboard hand) holds the T-grip handle with a comfortable grip whilst the bottom hand (outboard hand) holds the shaft with a half fist grip at the midpoint of the paddle. The paddling stroke begins with core rotation. Core rotation increases paddle reach and stroke length. Longer strokes increase the boat speed. Rotation starts with the outside hip pushing forward whilst the inside hip moves back. As the trunk rotates it flexes forward. The back is turned to face outboard at an angle to the boat. The bottom shoulder (outboard shoulder) moves forward and the top shoulder (inboard shoulder) moves back. Arms extend as the trunk rotates and flexes forward over the gunwale. The head and neck face forward throughout the paddling stroke.

At full trunk rotation and flexion the shoulders are stacked with the top shoulder over the bottom and the head above the gunwale. From this position a paddler can see the outside surface of the boat. The paddle is held close and square to the side of the boat, vertical to the water, with the bottom hand forward of the top. Body weight is transferred over the gunwale with full force onto the paddle blade by the top hand, arm and shoulder during water entry (the catch phase of the paddling stroke). The top hand pushes down on the handle along the shaft axis as the weight is transferred to the blade driving it to full immersion. Resistance and connection with the water must be maintained by the paddler throughout the catch phase of the paddling stroke.

At full blade immersion the pull phase of the paddling stroke begins with trunk counter rotation and leg pressure on the foot-ribs. The paddler uses stomach muscles to push with the feet and heels against the foot-ribs to increase paddle resistance and connection. Hips press forward as the paddler sits up and slides the boat. Core and back muscles fully engage. The top hand maintains pressure on the blade as the bottom hand pulls the body to the paddle. Hands and the paddle move in a vertical plane close to the side of the boat. For maximum resistance and connection the bottom hand stays above the water, keeps the blade fully submerged until the exit point is reached. Loss of resistance and connection before the exit causes splashing and water shovelling, thus reducing boat speed. At the exit the paddle must leave the water cleanly.

The exit begins when the paddle shaft is at mid-thigh. Both arms pull the blade from the water before the back of the seat is reached. The top hand in front over the water swings briefly into the boat as the blade exits and the recovery phase of the next paddling stroke begins. The paddle is snapped forward as the paddler moves smoothly to the set-up position and begins the next stroke.

For the description of the dragon boat paddling technique used in Australia and the terminology used in the thesis the author has developed standard definitions based in part on the terminology used in other paddle sports, discussions with elite level coaches and paddlers, observations and paddling experience (three decades of dragon boat paddling and participation in three world championships as a member of the Australian dragon boat team for his age group).

Overall the dragon boat paddling stroke can be defined by three action phases of the paddle; catch, drive and recovery. The catch phase has an air component from paddle set-up to water contact and a water component from water contact to full blade immersion. The drive phase is totally confined to water; it starts with full blade immersion and finishes when the force on the paddle in the water is reduced to zero. The recovery phase has a water component from zero force on the paddle to exit of the blade from the water and an air component from blade exit to the paddle set-up position. These five components blend together smoothly to form a sequence of movements that produce the action phases of the paddling stroke.

Dragon boat paddling is a cyclic process that needs to be examined in terms of paddle actions (catch, drive and recovery) and paddler movements in order to understand the process. The starting point is the standard seating position. Paddlers sit in pairs on wooden benches with their buttocks on the forward edge of the seat and their outside hip in contact with the side of the boat. Their backs are straight as the trunk flexes forward at an angle positioning the head over the gunnel. The head faces forward and above the gunnel throughout the paddling stroke. Eyes are focused on the drummer and the paddlers at the front (the strokes who set the stroke rate for the crew). The feet are placed under the seat in front with each heel resting on a foot rib. The inside leg must contact the rib; the outside leg may be tucked back for comfort. Hands hold and the arms control the orientation of the paddle during the paddling stroke. The bottom (outboard) hand holds the paddle at its mid-point with a loose hook grip between the thumb and fingers whilst the top (inboard) hand grips the handle firmly but not tightly with the fingers, palm and thumb.

From the standard seating position the paddling process begins. Arms thrust forward as the trunk begins to flex. The chest leads as the pelvis and thighs move the trunk forward to the set-up position. Body weight is transferred to the edge of the seat at the outside buttock. The top arm and shoulder elevate as the bottom arm and shoulder extend forward and down with trunk flexion over the gunnel to maximise reach at the paddle set-up position. The bottom arm is straight (elbow is fully extended) and the top arm is slightly bent (elbow is slightly flexed) with the bottom hand forward of the top and both hands outside the gunnel above the water.

At the set-up position the catch phase of the paddling stroke begins. The paddle is driven forward and down aggressively to the water and full blade immersion via a chopping action of the body produced by the stomach muscles, trunk flexion, inboard shoulder and top hand. The bottom arm remains fully extended and the top arm is slightly flexed. The bottom hand is forward of the top to maximise paddle reach and entry angle. The aggressive forward movement of the trunk continues with top hand and shoulder pressure on the paddle down along the shaft axis until full blade immersion is achieved. At this point the catch phase of the paddling stroke ends and the drive phase begins. Skilled paddlers produce no splash or noise during water entry.

The drive phase starts with trunk extension as the paddlers begin to sit up. Leg pressure is applied to the foot ribs via the heels as the stomach muscles engage to push the boat forward. Top hand pressure on the paddle is maintained and continues during the drive phase of the paddling stroke with a slightly bent (flexed) top arm held at chest height. The bottom arm is straight but not locked as the bottom hand moves parallel to the side of the boat above the water surface resisting, together with the top hand, the blade pressure generated by the trunk extension. The drive phase continues with top hand pressure, trunk extension and leg pressure as paddlers sit up and reach the standard seating position. At this point leg pressure against the foot ribs cease along with top hand pressure. The drive phase of the paddling stroke ends and the recovery phase of the paddling stroke begins.

The recovery phase of the paddling stroke begins with paddle exit and moves to the paddle set-up position where it ends. Paddle exit is achieved through a smooth forward flick of the top hand that clears the blade from the water. The top hand leads the paddle at the exit and the bottom hand follows. Skilled paddlers produce no splash or water shovelling at paddle exit. Forward motion of the trunk to the set-up position recommences. At set-up the next paddling stroke begins.

In summary dragon boat paddling consists of repetitive cyclic motions of the paddle mostly in the vertical plane. The paddling stroke has three action phases: catch, drive and recovery. Each phase transitions smoothly into the other. Recovery begins with the commencement of paddle exit from the water, continues with the forward movement of the paddle in air and ends with the paddle in its set-up position above the water from which the catch phase of the paddling stroke begins. The catch phase has two components; an air and a water component. During the air component the paddle is accelerated forward and down from the set-up position towards the water. When contact with the water is made the water component of the catch phase begins. The forward and down acceleration of the paddle continues until full blade immersion is achieved. At full blade immersion the catch phase of the paddling stroke ends and the drive phase of the paddling stroke begins. The drive phase continues with full blade immersion and paddle angular rotation until the exit position is reached at which point the recovery phase and the paddling cycle begins anew.

Comparison of the Canadian and Australian paddling technique shows considerable commonality and a few key differences. Both techniques have similar seating and set-up positions, locate the head over the gunnel, hold and move the paddle much the same way, apply top hand pressure to the paddle, use trunk flexion and extension, apply leg pressure to the foot ribs with the heel, enter the water without splashing, exit without shovelling and relax during recovery.

The main differences between the two techniques are that Canadian technique uses trunk rotation and engages the foot rib with both legs or the outside leg whereas the Australian technique uses no trunk rotation, emphasises trunk flexion and extension, and engages the foot rib with both legs or the inside leg. Engagement with both legs is preferred for then engagement of the foot rib with the dominant and stronger leg is assured. At paddle exit the Canadian technique uses both hands equally to extract the paddle from the water but in the Australian technique the top hand leads and the bottom hand follows as the paddle leaves the water.

1.4 A Brief history of the dragon boat festival

The origins of the dragon boat racing and the dragon boat festival are lost in antiquity. Scholars have put forward a number of explanations (Chao W., 1943; Huang, 1991; Chittick, 2011; Aijmer, 2016.). However the traditional explanation for several centuries has been that the Dragon Boat Festival and the dragon boat race commemorate the common peoples search for Qu Yuan. But a 1647 Chinese text (‘A Brief Description of the Dragon Boat Race in

Wu-ling' by Yang Ssii-ch'ang) translated by Chao (1943) reveals that whilst Yang the author of the text adopted the traditional explanation he also made it clear that for the common people the Dragon Boat Race was viewed as a solemn ceremony by which to expel evil. For centuries the fifth day of the fifth moon was known as the double-evil day. Only later did it become a day of celebrations. Yang's text provides a detailed description of the boats, their construction, the crew (fishing clans), spectators, customs, traditions and commentary on the dragon boat race as practiced in Hunan province in his lifetime.

Qu Yuan (B.C.340-363 to B.C.277-276) was a government official and a renowned poet in the state of Chu during the Warring States Period [475-221 B.C.] Chu was plagued by internal corruption and Qu Yuan advocated reform but his corrupt opponents forced him into exile. In 277 B.C. the Chu were destroyed by the state of Qin. In anger and sorrow for the catastrophe his beloved state suffered Qu Yuan committed suicide drowning himself in the River Mi Luo (Chang, 2008; Bridges & Ho, 2015).

During the late Han Dynasty (B.C.202 -A.D.220) and the Southern and Northern Dynasties (A.D.220 -589) the double-evil day, dragon boat racing and the legend of Qu Yuan evolved into one event; a day of happy celebrations and festivities (Huang, 1991; Chang, 2008). Thus the myth of the Dragon Boat Festival commemorating Qu Yuan was born.

1.5 Berth of the modern era of dragon boat racing

In 1976 the Hong Kong Tourist Association (HKTA) with the assistance of the Fishermen's Society of Hong Kong revived the dragon boat festival along with all its Taoist traditions in order to promote Hong Kong as tourist destination. Local and overseas teams were invited to participate. One Japanese team and over 300 local people took part in the dragon boat races of the revived festival. As a result of the cultural success the HKTA continued to support the event and by 1993 the entries had increased to 32 overseas and 128 local teams. Thus the

1976 event is regarded as the birth of the modern era of dragon boat racing (Sofield, & Sivan, 1994).

Through the participation and interest of overseas teams in the HKTA festival, the sport of dragon boat racing spread throughout the world. In 1990 the European Dragon Boat Federation (EDBF) was formed, followed by the International Dragon Boat Federation (IDBF) in 1991 and the Asian Dragon Boat Federation (ADBF) in 1992. Due to the growth of the sport, in 2007 the IDBF was recognised as the world governing body for the sport of Dragon Boat Racing by the General Association of International Sports Federations. Currently the membership of the IDBF stands at 80 countries. Thus in a little over 40 years a religious cultural event on the verge of extinction was transformed into an international team sport practiced all over the world by people of all ages in a social or competitive setting. At the highest level dragon boat racing is an extremely competitive sport. World nations and club crew championships are held every two years with the world nations' championships being held during odd years and the club crew championships being held in the even years (https://www.idbf.org/world International Dragon Boat Federation, accessed Nov 12, 2018; https://en.wikipedia.org/wiki/International_Dragon_Boat_Federation Wikipedia, accessed Nov 12, 2018).

1.6 Justification of the studies

Currently dragon boat racing does not have a body of literature that provides a biomechanical foundation for the sport. Coaching, as in most amateur sports, is based on experience, trial and error, and opinion. There is a need to understand the dragon boat paddling process from a scientific perspective and develop evidence based practices that coaches can use to improve racing performance. The studies in this thesis address the fundamentals needed to develop a biomechanical foundation for the sport and encourage the use of evidence based coaching.

1.7 General aims

The general aims for this thesis are as follows:

1. Gain an understanding of the paddling process in dragon boat racing.
2. Establish the phases and key events occurring within a dragon boat paddling stroke.
3. Define the dragon boat paddling stroke in terms of kinetic and kinematic parameters.
4. Identify the biomechanical parameters associated with skilled paddling.
5. Verify the coaching model used to teach paddlers a good dragon boat paddling stroke.
6. Establish the biomechanical parameters that differentiate paddlers from a more successful dragon boat racing crew from a less successful one.

Aims specific to a particular study are stated within the relevant section of that study.

1.8 Orientation to the thesis

The thesis is written with practitioners of the sport of dragon boat racing in mind. It is applied research. Elite coaches in sport have a need for research that is focussed on producing practical applications (Martindale & Nash, 2013; Gould, 2016) and the findings need to be communicated in simple plain language (Williams & Kendall, 2007). Researchers who can demonstrate practical knowledge of their field are more likely to have their research findings accepted by elite coaches (Martindale & Nash, 2013).

In all sports technique is of great importance. Technique analysis of sport movements and their effectiveness can lead to improved performance (Lees, 2002). Biomechanics is well suited to the assessment of sports in which success is determined by the execution of technical skill (Lees, 1999). For dragon boat racing paddling technique is a central issue. Over recent years through the efforts and interactions of coaches and paddlers a qualitative coaching model has emerged to teach paddlers a good dragon boat paddling stroke. The model as understood and summarised by the author states that a good dragon boat paddling stroke has maximum forward reach, a high set-up, an aggressive catch, a powerful drive, a quick exit and ~~a~~ smooth recovery. However the model is yet to be tested empirically. Study one (chapter 4) addresses this issue. Using the process of operationalism the fuzzy qualitative concepts of the coaching model are redefined in terms of measurable kinetic and kinematic parameters of the paddling stroke. These biomechanical parameters are measured under simulated racing conditions for paddlers of more and less skill. The results are analysed and compared statistically to ascertain the support for the coaching model.

Performance in dragon boat racing is measured at the crew level via race times. Average boat speed is the key factor determining success. Due to the standardisation of the boat and paddle, boat speed is determined by the power output of paddlers, their paddling technique and skill, and at the fundamental level, on the physics of paddle-water interaction. To understand boat propulsion in dragon boat racing we need to study the kinetics and kinematics of the paddle before we study the movements of paddlers. Therefore this thesis is focused on the kinetics and kinematics of the paddle under simulated dragon boat racing conditions.

To determine what differentiates a more successful racing crew from a less successful one, two boat crews, one more successful than the other, are tested in study two (chapter 5) via simulated racing conditions. The results are analysed and compared statistically to establish the kinetic, kinematic and temporal paddle parameters that differentiate the two racing crews.

In studies 3 and 4 the skill aspects of dragon boat paddling are addressed. Results from the simulated racing tests are analysed and compared statistically at the individual level on the basis of skill to establish in study three (chapter 6) the kinetic and temporal, and in study four (chapter 7) the kinematic paddle parameters that differentiate paddlers on the basis of skill.

Chapter 2 – Literature Review

Dragon boat racing is a flatwater sport that uses a single sided paddling technique. Other water sports that use single sided paddling include rowing, canoeing, outrigger and stand-up paddling. Kayaking uses a double sided technique and an aerofoil type paddle blade that moves laterally and longitudinally in the water so kayaking is excluded from the literature review. Rowing uses a fixed pivot point paddle (oar) that moves in an arc in the horizontal plane to produce propulsion and participants sit on a sliding seat therefore it is also excluded from the review. Dragon boat racing, canoeing, outrigger and stand up paddling all use a freely moving paddle that moves mostly in the vertical plane during propulsion. The similarities and differences between each of these sports will be discussed in the following sections. Peer reviewed journal articles for each sport were located via the database search system of Victoria University library and reviewed.

2.1 Canoeing

Using the search term “canoeing” 594 peer reviewed journal articles were located via the Victoria University library database search system. The number of articles found via selected search terms were as follows; 75 under “canoe racing”, 24 under “canoe biomechanics”, 19 under “canoe kinetics”, 18 under “canoe kinematics” and 12 under “canoe flat water”. Canoeing is an Olympic sport (C1, C2, and C4) but the number of research papers available is surprisingly small.

Flatwater canoeing is the closest sport to Dragon boat racing (J. Baker 2007, Australian Institute of Sport, personal communication, 10 May). Both sports use drag based paddles with flat blades and paddle on one side of the boat. The paddling stroke is predominantly in a vertical plane aligned with the racing direction especially so when the paddle is in the water. The mechanism of propulsion is the same in both sports. However there are differences - the main one being body position during paddling; dragon boat paddlers sit whereas canoe paddlers kneel as they paddle. There are other differences. Canoeing is predominantly an individual activity (C1) but pairs (C2) and fours (C4) though less popular are also a part of the sport. Dragon boating is a team only sport with 10 or 20 paddlers making up a racing crew. Synchronicity and coordination between the paddlers is required. Timing is a key issue for the dragon boat paddling technique. Differences in equipment also exist between the sports. Canoes can be individualised by design within a standard specification whereas in dragon boat racing the boats must be identical and manufactured to a standard specification. At high level competitions the dragon boats used must come from one single manufacturer. There are differences also in the paddles used by each sport. Canoe paddlers are free to use a paddle of any length and a blade of any shape or size. However in dragon boat racing the paddle blade is standardised in shape and size but the paddle length may vary from 1.05 to 1.30 m.

The library search for research papers on canoeing located a number of documents that were of some relevance to dragon boat racing. Two papers examined paddle blade designs (Sumner et al., 2003; Campbell-Richie & Selamet, 2010). Sumner et al., (2003) compared three kayak paddle blades of different design (Conventional, Norwegian, Turbo) in a low speed wind tunnel and found that the drag coefficient were mostly independent of the blade design and were very similar to that of a flat plate. Campbell-Richie & Selamet (2010) compared the blade designs of two canoe sprint paddles (Macon and rectangle) against two Asian paddles (dragon boat and chundan). The pressure distribution on the face of the paddle blades were calculated via computational fluid dynamics whilst the coefficient of drag and drag forces were investigated experimentally in a water tunnel. Unfortunately the results conflicted with each other and there was no correlation between the two methods of evaluation. However the drag factors obtained from the water tunnel tests were similar to those obtained by Summer et al., (2003).

Plagenhoef (1979) collected slow motion film records of Olympic and world champion canoe and kayak paddlers over a nine year period and analysed the data with the aim of determining the factors that explain the success of champions. He measured stroke times, paddle angles, body positions and traced the absolute motion of the paddle under water. His findings were paddle entry 50 – 60 degrees, trunk angle at entry 47 – 58 degrees and strokes times 0.77 – 0.86 s. The best paddlers entered their blade square and produced no slippage or drag on the paddle: the throat of the blade remained stationary with respect to the water surface. Movement of the top hand relative to the canoe was minimal during the water phase of the paddle stroke. There was no one ideal style of paddling. Style was determined by the strength, anthropometry and comfort of the paddler. Body movements of paddlers could vary and yet the same efficient paddle motion in water would be produced. Motion of arm joint centres relative to the boat, paddle path patterns, absolute motion of the paddle in water and stroke times were the most useful measures to differentiate levels of performance. For an efficient paddling stroke Plagenhoef (1979, p456) stated that the paddle ‘blade is actually stationary in the water’. He concluded that the tracing of absolute motion of the paddle blade in water is sufficient on its own to differentiate good paddlers from poor paddlers – no other information is required (Plagenhoef 1979, p459).

Two studies examined muscle activation via EMG (electromyography) in canoe paddlers (Court, Davis & Atha, 1980; Pelham, Burke & Holt, 1992). Court et al., (1980) studied paddling technique and Pelham et al., (1992) aimed to develop an off-water conditioning program for paddlers. For this Pelham et al., (1992) tested two male international level paddlers on a C-1 ergometer and on water but only the ergometer findings were reported. It was acknowledged that differences in the level of muscle activity may arise but ergometer paddling was considered to be representative of on-water paddling. The muscles used were reported and an exercise program to develop endurance was recommended.

Court, Davis & Atha (1980) noted that there was an abundance of coaching advice but no factual information on the technique of racing the Canadian canoe (C1). Whilst this statement was made nearly 40 years ago it is still applicable today. The leading coaches of the time offered differing advice; Granek (1969) advocated trunk flexion whilst Antal (1978) preferred the trunk rotation and shoulder lift technique. In response Court et al., (1980) undertook a broad ranging study to measure the kinetic, kinematic and electromyographic characteristics of C1 paddling using paddlers of different levels of skill and experience. The kinetic characteristics were obtained via a strain gauged paddle that measured the bending and torsional forces on the paddle shaft during paddling. Three-dimensional kinematics of paddling was recorded by a stationary movie camera. Electromyographic data from ten muscle groups thought to be responsible for body motion were collected simultaneously during the paddling tests. An external timing device was used to synchronise the collected data and maintain a common stroke rate for all the paddlers.

Difference in technique between paddlers of four levels of skill and experience are illustrated in Figure 2.1-1. The highly skilled paddler uses a more upright stance, has a greater angle of paddle entry, higher top hand position, constant knee flexion, straighter arms throughout the stroke and a greater range of paddle angular movement than the other paddlers. The other less skilled paddlers appear to vary their stance, knee flexion and top arm flexion angles. They finish with the paddle closer to the body indicating a lower level of skill compared to the highly skilled paddler with a more efficient paddling technique.

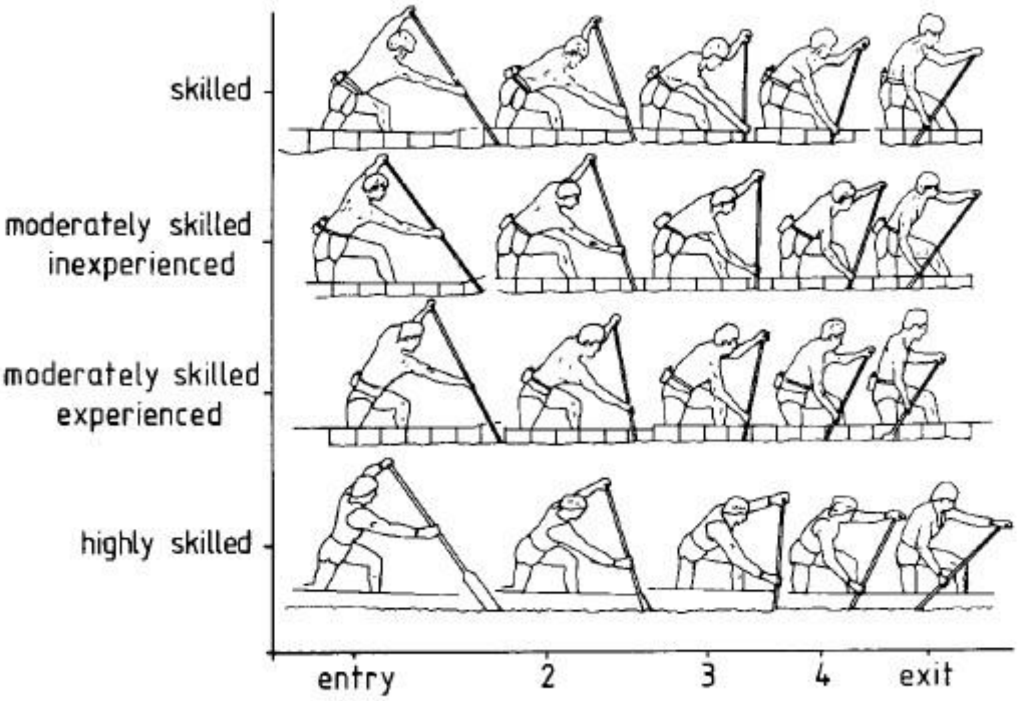

Fig. 4 *Sagittal view tracings taken at selected equal percentages of the power phase*

Figure 2.1-1: Comparisons of paddle and body positions derived from filmed data for paddlers of differing skill as a function of time during a paddling stroke [Fig. 4, Court et al., (1980)].

The vertical lines in Figure 2.1-2 crossing the EMG data mark the time of blade entry and blade exit for the paddling stroke. Muscles are shown arranged vertically in the order of activation. It can be seen from the vertical lines that the duration of propulsion (water time) was substantially less for the skilled paddler (0.667 s versus .0750 s). These times represent 55 and 62 percent of the stroke time respectively. Measurement of overall muscle activation during propulsion showed that the moderately skilled paddler worked for 75 percent of the time whilst the skilled paddler worked only for 64 percent. Muscle activation in terms of order, duration and intensity as shown in the charts are noticeably different for the two paddlers. The skilled paddler had more recovery time, hence better work efficiency and lower stress than the moderately skilled paddler. The amplitude of muscle activation was substantially less for the skilled paddler.

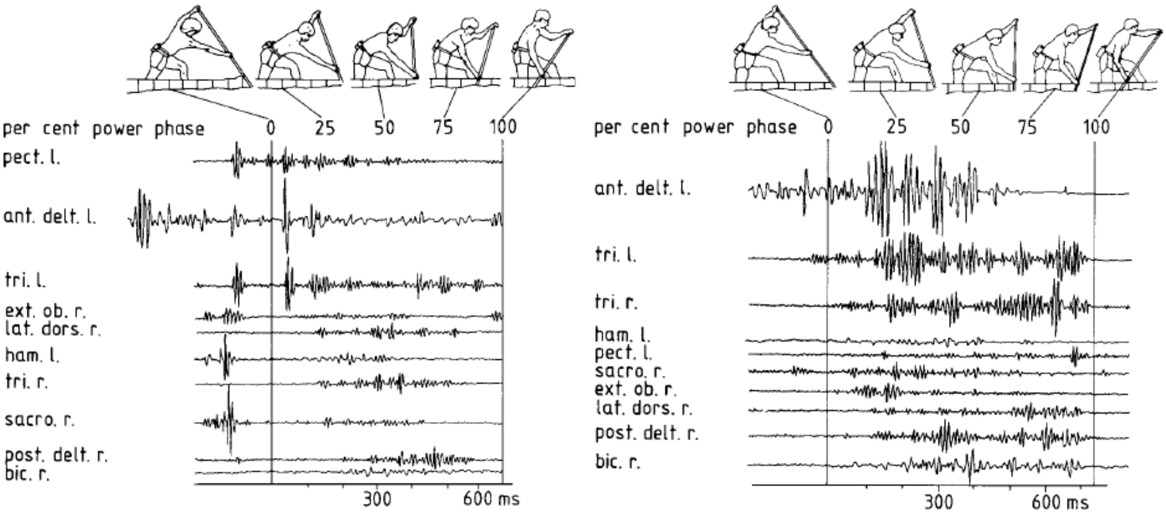

Fig. 5 *EMG activity during power phase for skilled subject*

Fig. 6 *EMG activity during power phase for moderately skilled subject*

Figure 2.1-2: Comparison of muscle activations as a function of time between a skilled and moderately skilled paddler during a paddling stroke [Fig. 5 and Fig. 6, Court et al., (1980)].

The substantial differences in the forces generated by each paddler are seen in Table 2.1-1 below. The skilled paddler (subject X) applied higher forces to the paddle in the early part of the stroke than the moderately skilled paddler (subject Y) but substantially less in the latter part of the stroke. The peak force was reached earlier in the stroke by the skilled paddler who produced a higher rate of force increase on paddle entry and higher rate of force reduction on paddle exit.

Table 2.1-1: Comparison of the paddle forces generated by a skilled paddler (subject X) and a less skilled paddler (subject Y) during a paddling stroke [Table 3, Court et al., (1980)].

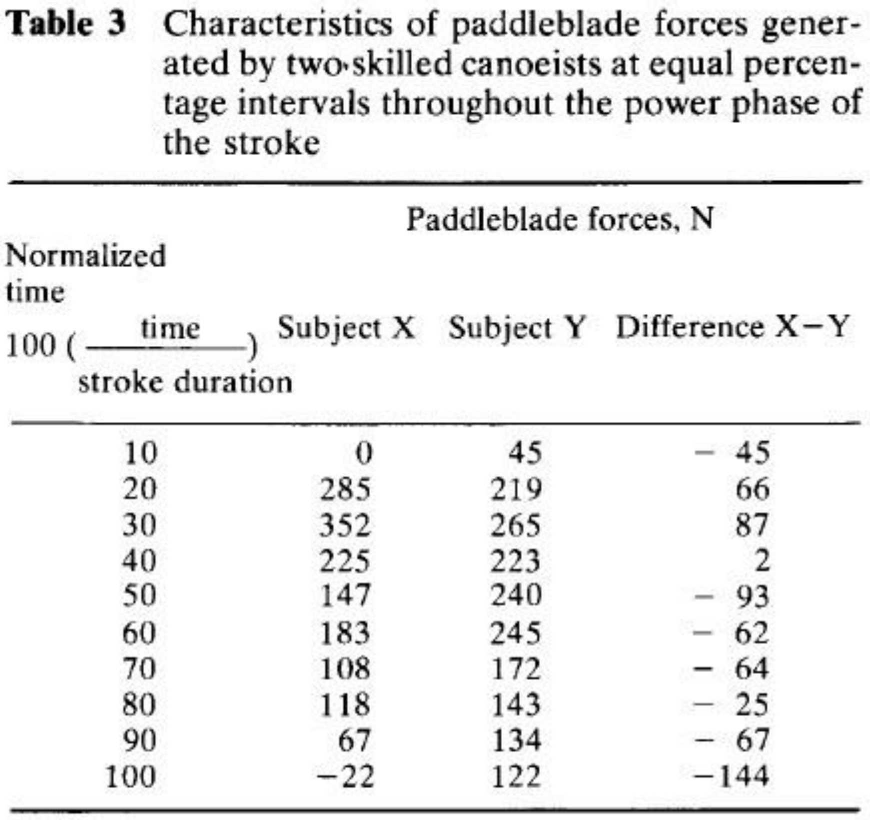

Table 3 Characteristics of paddleblade forces generated by two skilled canoeists at equal percentage intervals throughout the power phase of the stroke

Normalized time $100\left(\frac{\text{time}}{\text{stroke duration}}\right)$	Paddleblade forces, N Subject X	Subject Y	Difference X−Y
10	0	45	−45
20	285	219	66
30	352	265	87
40	225	223	2
50	147	240	−93
60	183	245	−62
70	108	172	−64
80	118	143	−25
90	67	134	−67
100	−22	122	−144

The differences noted above are shown more clearly in Figure 2.1-3 below. The skilled paddler produced a sharp triangular shaped force pattern for the paddling stroke whereas the moderately skilled paddler produced a trapezoidal shaped. Force increase at the start of the stroke was higher for the skilled paddler as was the peak force. Around 500N was produced by the skilled paddler whereas the moderately skilled paddler produced less than 400N.

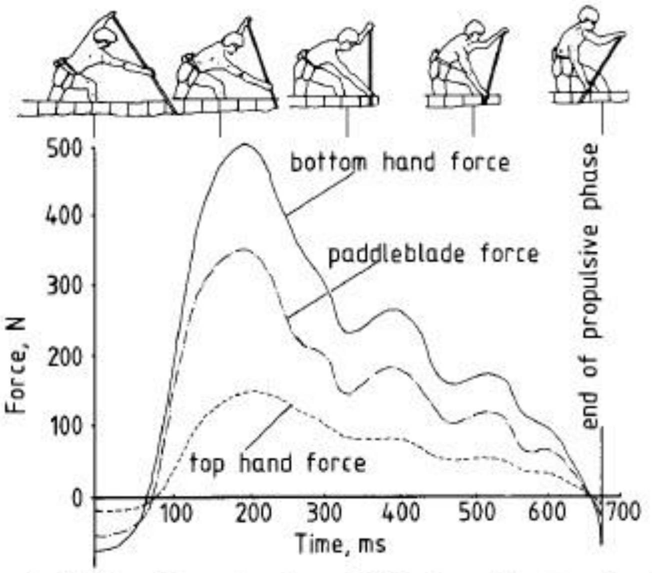

Fig. 9 *Subject X top hand, paddleblade and bottom hand forces during the power phase of the stroke*

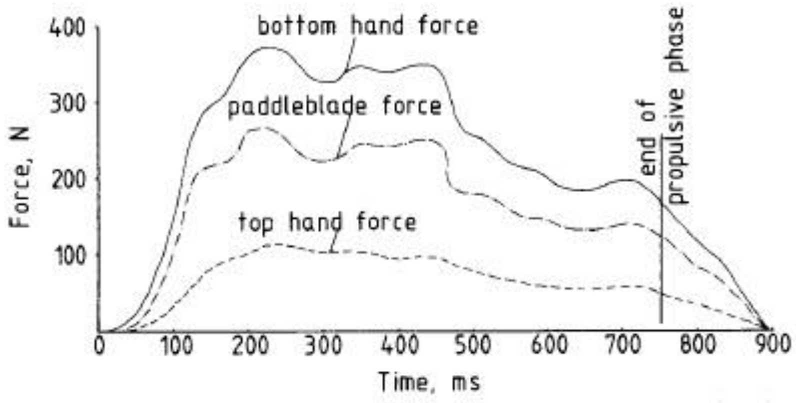

Fig. 10 *Subject Y top hand, paddleblade and bottom hand forces during the power phase of the stroke*

Figure 2.1-3: Comparison of the paddle forces on the paddle blade, top hand and bottom hand between a skilled and a moderately skilled paddler during a paddling stroke [Fig. 9 and Fig. 10, Court et al., (1980)].

2.2 Outrigger paddling

The library database search for “outrigger paddling” peer reviewed journal articles located 11 documents but no papers on the subject of on-water paddling kinetics and kinematics. Google Scholar located a PhD thesis (Sealey, 2010) that examined outrigger paddling ergometry. Sealey, Ness & Leicht (2011, 2012) studied the kinematic paddling technique of outrigger paddlers with respect to stroke rate, stroke length, propulsive and recovery times, trunk flexion and trunk rotation and compared the physiological demands of self-selected and imposed stroke rates for outrigger paddling on an ergometer. Kerr et al., (2008) also used an ergometer. They compared the physiological responses of outrigger paddlers to a graded paddling test protocol.

Humphries et al., (2000) studied the Kinanthropometric and physiological characteristics of outrigger canoe paddlers whilst Stanton, Humphries & Abt (2002) surveyed the training habits of Australian outrigger paddlers who attended the 1998 Australian Outrigger Canoe Titles. Stanton (1999) developed a periodised year-long strength training program for outrigger paddlers meeting the needs of injury prevention and performance improvement. Haley & Nichols (2009) surveyed the injuries and medical conditions affecting competitive outrigger paddlers in Hawai’i.Canyon and Sealey (2016) systematically reviewed outrigger paddling literature but located no papers on the biomechanics of on-water outrigger paddling.

Dascombe et al., (2002) carried out a tethered OC-1 outrigger canoe paddling test and found a significant relationship between the peak paddling force and strokes rates of 50 to 90 spm (strokes per minute) but reported no force data. Caplan (2008) modelled the boat velocity of an OC-1 outrigger canoe mathematically and validated it against the filmed kinematics of a 500m race performed by an elite female paddler.

2.3 Stand-up paddling

For the search term “stand-up paddling” 7 peer reviewed journal articles and a PhD thesis were located via the Victoria university library database search system. Two conference papers from Ruess, Kristen, Eckelt, Mally, Litzenberger & Sabo (2013a, 2013b) investigated the activity of the trunk and leg muscles during stand up paddle surfing and the suitability of stand up paddling for endurance and balance training. A conference paper by Yukawa, Iino & Fujiwara (2015) examined the use of GPS, heart rate and paddling cadence monitors along with an anemometer measuring the wind speed and direction to study the effort in stand up paddling. The PhD thesis of Schram (2015) analysed the new sport of paddle boarding and produced four peer reviewed articles [Schram, Hing, Climstein & Walsh (2014); Schram, Hing & Climstein (2016a, 2016b); and Schram & Furness (2017)].

However none these documents contained any information on the kinetics or kinematics of the paddle during stand up paddleboard paddling. When such information becomes available, it will be of interest to compare paddle kinetics and kinematics with that of dragon boat paddling.

2.4 Dragon boat paddling

The Victoria University library database search system located 121 peer reviewed articles for the search term “dragon boat”. Upon review 35 articles were found to deal with the subject of breast cancer patients and the benefits of dragon boat paddling. Fifteen dealt with historical and cultural aspects of dragon boat racing and the dragon boat festival. Ten were concerned with the field of exercise physiology, psychology, injury and caffeine supplementation. A total of seven documents covered the subject of dragon boat biomechanics: one journal article (Ho, Smith & O’Meara, 2009), three conference papers (Gomory, Ball & Stokes, 2011; Gomory, Stokes & Ball, 2012; Ho, Smith & Sinclair, 2012) and three conference abstracts

(Ho, Smith & Funato, 2009; Ho, Smith & O'Meara, 2008; Pease, 1997).

The abstract by Pease (1997) was the only published information available on the performance of dragon boat paddlers in actual dragon boat races. All the other available literature was concerned with testing paddlers in simulated races on water (Gomory, Stokes & Ball, 2012; Ho, Smith & O'Meara, 2009) or on ergometers of one form or another (Ho, Smith & Funato, 2009; Ho, Smith & O'Meara, 2008; Ho, Smith & Sinclair, 2012). Pease (1997) studied the kinematics of large and small framed paddlers at the 1997 Hong Kong World Cup for two consecutive paddling strokes via a stationary video camera at 50 Hz but reported qualitative statements only in the abstract. He stated that small framed paddlers tended to have high stroke rates around 95 spm, shorter stroke lengths and shorter boat travel per stroke, with a larger angle of paddle entry than large framed paddlers who tended to have a stroke rate of about 80 spm with greater boat travel per stroke, longer stroke lengths and a smaller angle of paddle entry.

Ho et al., (2008) in their study used a specially constructed dragon boat simulator to measure the foot forces of two competitive dragon boat paddlers for 10 consecutive paddling strokes. The simulator replicated the seating geometry of a dragon boat and used the air-resistance mechanism of a Concept 2D rowing machine to provide paddling resistance. Whilst Ho et al., (2008) called this equipment a dragon boat simulator in reality it was just an ergometer with dragon boat seating. It is unlikely that paddling on an ergometer with dragon boat seating in a laboratory is equivalent to paddling on-water in a dragon boat. The loading of the paddle by the air-resistance mechanism of a Concept 2D rowing machine is unlikely to replicate the force-time relationship achieved in on-water paddling. In rowing it has been well documented that there are differences between ergometer and on-water rowing with respect to physiological, electromyographic and kinematic responses (Bazzucchi et al., 2013; Fleming, Donne and Mahoney, 2014; McNeely, 2012; Vogler, Rice and Gore, 2010). Thus the expectation is that a similar situation would apply to dragon boat ergometer and on-water paddling.

Ho et al., (2008) presented the kinetic data of their study in graphical form for the front and back foot of a male and female paddler with respect to spatial orientation and percentage of stroke displacement. However feet positions in dragon boat paddling are not fixed so the reported data are only representative of the two paddlers tested. All possible feet combinations relative to the seat are used in dragon boat paddling; two feet forward, inboard foot forward and outboard foot back and outboard foot forward and inboard foot back. The feet may be flat on the floor of the boat or on the footrests with contact via the ball of the feet or with the heel. Many elite paddlers use the two feet forward position with heel contact with the foot rests. Thus the findings of the Ho et al (2008) study are likely to be of limited use.

The Ho et al., (2009) conference abstract compared the 3D kinetics on a paddling ergometer with the specially constructed dragon boat simulator described in the Ho et al., (2008) abstract. No numerical data were reported but in conclusion it was suggested that due to the observed differences in the 3D kinetics the paddling ergometer did not accurately represent on-water dragon boat paddling. However in reality the comparison was not between on-water dragon boat paddling and an ergometer but between two types of ergometers. The critique of the equipment in the Ho et al., (2008) study also applies to the equipment in the Ho et al., (2009) and Ho et al., (2012) studies.

The Ho et al., (2012) study used a similar dragon boat seat simulator with a Vermont paddling adaptor attached to a Concept 2D rowing ergometer to study the kinematics of dragon boat paddlers with respect to stroke rate for 10 consecutive strokes. Twenty dragon boat paddlers (twelve female, eight male) having different levels of skill and experience were tested at stroke rates of 40, 50 and 60 spm. As the stroke rate increased there was a significant decrease in stroke length and an increase in drive to stroke time ratio. The average stroke length decreased from 1.49 m at 40 spm to 1.40 m at 60 spm and the average drive to stroke time ratio increased from 54.3 to 57.4 percent for the respective stroke rates. Lumbar, hip, shoulder and elbow joint angles at entry and exit and range of motion were also reported by Ho et al., (2012).

However these results were presented in bar chart format and not in numerical form. They observed and noted that no significant change in trunk and shoulder range of motion, no change in trunk medial rotation or hip flexion at paddle entry were observed with increasing stroke rate. At higher stroke rates elbow flexion at paddle entry and the range of elbow motion were significantly higher but the range of hip motion was significantly less. For the highest stroke rate tested shoulder flexion at paddle entry, trunk lateral rotation and hip extension at paddle exit were all significantly less and elbow flexion was significantly more than for lower stroke rates. The number of significant changes in joint angles at paddle exit was greater than at paddle entry.

The stroke rates (40, 50 and 60 spm) used by Ho et al., (2012) are significantly below those used in dragon boat racing. Pease (1997) reported stroke rates of 80 and 95 spm, Ho et al., (2009) reported average stroke rates of 86 and 87 spm whilst Gomory et al., (2012) reported average stroke rates of 69 to 72 spm. Whether any of the kinematic findings of the Ho et al., (2012) study, derived from ergometer simulated paddling at such low strokes rates is likely to be useful to practitioners of the sport, is questionable.

Kinetic and kinematic data from real-world on-water dragon boat paddling is available in the journal article of Ho et al., (2009) and the conference papers of Gomory et al., (2011, 2012). Ho et al., (2009) studied the paddle forces, paddle and paddler movements developed by elite and sub-elite paddlers during ten consecutive paddling strokes video recorded at 50 Hz via a *moving* camera. Paddlers were classified as elite or sub-elite on the basis of a ranking score calculated from years of experience, state or national representation, performance trials and coach ranking. Gomory et al., (2012) studied the paddle forces and paddle movements of a single paddling stroke video recorded via a *stationary* camera for male and female paddlers classified as being skilled (state, national or international) or club level paddlers. A stationary camera was used to enable paddle motion to be studied in a stationary reference frame with respect to the water. Ho et al., (2009) used a moving reference frame in order to study paddle and paddler motion relative to the boat.

The method of synchronisation between the kinetic and kinematic data was different for the two studies. Gomory et al., (2012) achieved synchronisation objectively via a light flash that was recorded by the video camera and the trigger signal that was recorded by the paddle force data collection system. Since the kinetic and kinematic data were both recorded at 200 Hz the temporal relationship between them was established within an accuracy of 0.005 s. Ho et al., (2009) used a subjective circuitous method to synchronise their kinetic and kinematic data. Using their video data, strokes were counted from paddle entry to locate the 10 consecutive strokes to be evaluated and then the curve for paddle angle-time was correlated with the force-time curve. This method of establishing the temporal relationship between the kinetic and kinematic data is subject to human error and therefore is unreliable. Paddle entry for Ho et al., (2009) was defined by the initiation of force on the paddle. However this is an erroneous assumption that puts the kinetic data displaced relative to and not synchronised with the kinematic data. Study 3 (Chapter 6) of this thesis shows that force initiation starts at paddle set-up and that the force on the paddle at water contact is substantial thus the Ho et al., (2009) assumption is false.

Kinetic results for Ho et al., (2009) and Gomory et al., (2012) are summarised in Table 2.4-1 and Table 2.4-2 below. The paddle kinetics in both studies for the rates of force development, maximum force, average force and propulsive impulse were higher for the more skilled paddlers.

Table 2.4-1: Kinetic data summarised from Ho et al., (2009).

GROUP STATISTICS		Ho elite		Ho sub-elite		One-tail
Test parameters	Units	Ave	CI	Ave	CI	p value
Stroke rate	spm	87	2.0	86	2.0	NA
Force rate of development	N.kg$^{-2/3}$/s	182	60	148	36	0.27
Peak propulsive force	N.kg$^{-2/3}$	16.3	4.8	11.4	2.6	0.052
Average propulsive force	N.kg$^{-2/3}$	7.9	2.8	5.5	1.4	0.084
Mean to peak force ratio	ratio	0.48	0.02	0.48	0.02	0.96
Drive to recovery time ratio	ratio	0.56	0.02	0.51	0.02	0.17
Stroke impulse	N.s.kg$^{-2/3}$	3.0	0.9	1.9	0.4	0.026

Table 2.4-2: Kinetic data summarised from Gomory et al., (2012).

GROUPSTATISTICS		Club male		Skilled male		Club female		Skilled female	
Test parameters	Units	Ave	SD	Ave	SD	Ave	SD	Ave	SD
Stroke rate	spm	69	4	68	6	70	2	72	3
Force rate of development	N/s	1570	407	2620_{L}	1090	1100	380	2250^{*}_{L}	690
Maximum paddle force	N	252	58	323_{L}	91	157	44	221^{*}_{L}	43
Average paddle force	N	134	23	159_{L}	28	74	22	107^{*}_{L}	20
Mean to peak force ratio	ratio	0.54	0.07	0.5	0.07	0.47	0.07	0.48	0.02
Minimum paddle force	N	-43	17	-62	34	-36	12	-28	9
Propulsive impulse	N.s	59	14	75_{L}	21	31	9	44^{*}_{L}	10
Propulsive impulse rate	N.s/s	68	16	84_{L}	21	36	11	53_{L}	12

‘Cohen's d’ effect size L = Large (>0.8). Statistical Significance * = p<0.05

In the Ho et al., (2009) study the average mean to peak force ratio was the same for both the elite and sub-elite group. For Gomory at al., (2012) it was higher for males than for females. Compared to Ho et al., (2009) the mean to peak force ratio in the Gomory et al., (2012) study was higher for males and for females almost identical with that of Ho et al., (2009). Stroke rates were approximately twenty percent higher for Ho et al., (2009) paddlers than for the Gomory et al., (2012) paddler groups indicating a difference in paddling technique. Skill levels had no effect on stroke rates in either study.

In terms of statistical testing the Ho et al., (2009) study found no significant differences between the kinetics of elite and sub-elite paddlers except for stroke impulse which was significantly higher for the elite group ($p = 0.026$). Gomory et al., (2012) found that the rate of force development, maximum paddle force, average paddle force and stroke impulse along with impulse workload were all significantly higher ($p < 0.05$) with a large effect size ($d > 0.8$) for skilled female paddlers. For skilled male paddlers these test parameters were not significantly different however each parameter had a large effect size.

The kinetic results of Ho et al., (2009) were presented in allometric form. Each test result was divided by the body mass of the paddler raised to the power of two-thirds so as to normalise the data and remove the confounding effects of gender and unmatched groups (elite: three male, three female; sub-elite: two male, four female). Gomory et al., (2012) used standard units hence direct numerical comparisons between the two studies could not be made.

Six test parameters in were common for both studies; stroke rate, rate of force development, maximum paddle force, average paddle force, mean to peak force ratio and stroke impulse. Ho et al., (2009) reported an additional test parameter, drive to recovery time ratio, being an average of 0.56 for elite and 0.51 for sub-elite paddlers however the difference was not of statistical significance. Drive for Ho et al., (2009) was defined as the time during which the paddle was in the water. Thus the drive to recovery time ratio was in fact the water to air time ratio of the paddling stroke.

Gomory et al., (2012) reported two additional test parameters in their study, minimum force on the paddle and propulsive impulse rate. The minimum force on the paddle occurred in the recovery (air) phase of the paddling stroke and was negative indicating that paddle force was in the opposite direction to the propulsive force produced on the paddle in the water. This negative force was due to the inertial acceleration of the paddle in air towards the paddle set up position for the subsequent paddling stroke. It ranged from an average of -28 N for skilled females to -62 N for the skilled males with the club gender results being within the skilled paddler range.

Propulsive impulse rate is a parameter that combines stroke impulse with stroke rate. It was used to give an indication of the effort of paddling since it was not possible to measure the actual work output. A paddler who produces a given impulse at a higher stroke rate is working harder than a paddler who produces the same stroke impulse at a lower stroke rate. Results for the propulsive impulse rate were statistically significant for skilled female paddlers and the effect size was large for both male and female skilled paddlers.

With regard to kinematic data, none of Ho et al., (2009) results were statistically significant. Trunk flexion angle (41 versus 48 degrees) with $p = 0.06$ was almost significant. For the Gomory et al., (2012) study, the results show that stroke length was significantly greater for all skilled paddlers with a large effect size. The horizontal blade displacement on the water surface and the paddle angles at minimum force, zero force in water and water exit were all significantly greater for skilled female paddlers.

The kinematic data for Ho et al., (2009) and Gomory et al., (2012) are shown in Table 2.4-3 and Table 2.4-4.

Table 2.4-3: Kinematic data summarised from Ho et al., (2009).

GROUP STATISTICS		Ho elite		Ho sub-elite		One-tail
Test parameters	Units	Ave	CI	Ave	CI	p value
Elbow flexion angle entry	deg	16	2	16	8	0.3
Elbow flexion angle exit	deg	71	19	59	33	0.19
Paddle angle water entry	deg	40	7	39	4	0.81
Paddle angle water exit	deg	-63	4	-63	1	0.73
Shoulder angle paddle entry	deg	114	7	119	4	0.13
Shoulder angle paddle exit	deg	0	30	-13	6	0.4
Stroke length	m	1.3	0.1	1.2	0.1	0.23
Stroke rate	spm	87	2	86	2	NA
Trunk flexion angle entry	deg	41	8	48	3	0.06
Trunk flexion angle exit	deg	21	4	23	3	0.2

Table 2.4-4: Kinematic data summarised from Gomory et al., (2012).

GROUPSTATISTICS		Club M		Skilled M		Club F		Skilled F	
Test parameters	Units	Ave	SD	Ave	SD	Ave	SD	Ave	SD
Boat displacement per stroke	m	3.18	0.19	3.32	0.21	3.01	0.36	3.22	0.16
Maximum force angle	deg	0	7	9^{*}_{L}	7	7	4	6	4
Minimum force angle	deg	-50	13	-57	7	-50	14	-63^{*}_{L}	6
Horizontal blade displacement	m	-0.32	0.13	-0.28	0.31	-0.25	0.12	-0.07^{*}_{L}	0.03
Stroke length	m	1.59	0.17	1.81^{*}_{L}	0.12	1.47	0.15	1.76^{*}_{L}	0.15
Stroke rate	spm	69	4	68	6	70	2	72	3
Stroke reach	m	1.27	0.17	1.34	0.07	1.27	0.09	1.31	0.1
Water entry angle	deg	34	6	34	6	33	4	31	3
Water exit angle	deg	-54	9	-58	4	-50	6	-61^{*}_{L}	5
Zero force angle in air	deg	27	11	23	7	19	13	28	4
Zero force angle in water	deg	-51	8	-52	9	-41	5	-57^{*}_{L}	5

‘Cohen's d’ effect size **L** = Large (>0.8). Statistical Significance ***** = $p<0.05$

In summary the studies by Ho et al., (2009) and Gomory et al., (2012) provided numerical data for the first time on the kinetics and kinematics of on-water dragon boat paddling at racing pace. The results indicated that skill levels affect paddling performance and that higher skilled paddlers perform better. However each of the studies had limitations. In both studies the sample size was small. The Ho et al., (2009) study lacked gender balance between the test groups. Gender balance in the Gomory et al., (2012) study was present but p values and effect sizes were not reported. But when test parameters were statistically significant ($p < 0.05$) or had a large effect size ($d > 0.8$) this was noted in the results table. For the Ho et al., (2009) study only one significant difference between elite (three male, three female) and sub-elite (two male, four female) paddlers were found. The stroke impulse was significantly higher for the elite group. This situation of so many non-significant results may have arisen from an inadequate skill classification system, from the use of test parameters that were not sensitive to skill or from the small number of test participants taking part in their study. The like causes are the complex skill classification system noted earlier and the small number of participants.

2.5 Implications of the literature

The review of the literature revealed a number of research ideas; lessons and findings from the sport of canoeing and dragon boat paddling that are relevant to the thesis. Plagenhoef�What's (1979) approach in measuring stroke times, paddle angles and the motion of the paddle in water for canoeing is directly applicable. These variables need to be adopted as test parameters for the thesis. The statement, that for an efficient paddling stroke, the paddle ‘blade is actually stationary in the water’ (Plagenhoef, 1979, p456) needs to be operationalised as a test parameter.

From the force-time data of Court, Davis & Atha (1980) it is evident that the force measuring test equipment must to be able to measure paddling forces of at least 500 N. It is also evident that rate of force increase, maximum force and rate of force decrease, along with a force shape factor need to be made test parameters. Timing aspects of the paddling stroke also need to be operationalised as test parameters of the thesis.

Presentation of data for on-water dragon boat paddling in the journal article of Ho et al., (2009) and the conference papers of Gomory et al., (2011, 2012) demonstrates a need to standardise definitions of terms and test variables to avoid confusion and errors in research findings. The force-time chart in Court, Davis & Atha (1980) and Gomory et al., (2012) implies a need for a theoretical model of the paddling stroke applicable to canoeing and dragon boating. The model through its parameters and concepts needs to reflect the actual paddling process.

Participants in the Ho et al., (2009) study were classified as elite or sub-elite paddlers on the basis of a ranking score calculated from years of experience, state or national representation, performance trials and coach ranking. For Gomory et al., (2012) state, national or international competitors were classified as being skilled paddlers whilst all other paddlers were classified as club level participants. The Ho et al., (2009) study found no significant differences between the elite and sub-elite paddlers for kinetic and kinematic parameters except for stroke impulse. In the Gomory et al., (2012) study five kinetic and five kinematic parameters were found to be significant.

These results highlight the importance of proper group selection for statistical analysis. The large difference in the number of significant results found between the two studies may to be due to the use of an unsatisfactory skills classifications system by Ho et al., (2009). For the thesis the system used by Gomory et al., (2012) will be the one used.

CHAPTER 3 – METHODS

This chapter addresses the general approach to research in the thesis. Items covered include research strategy, selection of test subjects, equipment used, measurement calibration, synchronisation between data collection devices, test procedures, theoretical model of the paddling stroke, paddle path in water and the associated paddle forces, definitions of test terms, selection of test parameters, data analysis and statistical evaluations. More specific methodology details particular to each study will be described in the methods section of that study (Chapters 4 to 7).

3.1 Research strategy

The main aim of this thesis is to gain an understanding of the paddling process in dragon boat racing and to identify the biomechanical characteristics that differentiate more successful higher skilled paddlers from those less successful and less skilled. Therefore a naturalistic observational quasi-experimental descriptive study (Kirk, 2013) using availability sampling (convenience sampling) was planned and carried out. The general investigative approach of the thesis is to examine the effect of paddler skill and team success (independent variables) on the paddle kinematic and kinetic parameters (dependent variables) measured via simulated dragon boat races.

Ideally a probability sampling method (one in which every member of the population under study has an equal chance of being selected), would have been preferred as this would enable unbiased samples to be obtained and the generalisation of the study findings to be free of bias thus making them more valid. However it is not possible to use probability sampling as ethical consideration require participants under study to be volunteers. Only a subset of the dragon boat paddling population was available for sampling; those living in Melbourne who were willing to participate and those who met the acceptance criteria. Hence a nonprobability sampling method, availability sampling, was chosen for the thesis studies.

Availability sampling provides the opportunity to select sub-groups of interest from a population. Since this case selection method is non-random it gives rise to exclusion bias and places limits on how information from this sample can reflect the general population. The two sub-groups of interest in this study are ‘more skilled’ and ‘less skilled’ paddlers, and, ‘more successful’ and ‘less successful’ racing crews.

In order for the studies to provide meaningful results there has to be sufficient differences between the sub-groups to enable statistical differentiation. How this requirement was met is explained in the next section.

3.2 Participants

Dragon boat racing is a team sport. Hence the biomechanics of dragon boat paddling needs to be studied in a team context under representative racing conditions. Whilst physically it is possible for a paddler to paddle a dragon boat on their own for a short distance, the boat speed and paddling technique would be unrepresentative compared to a boat crew of twenty paddlers taking part in a race. Therefore to be representative, local dragon boat clubs from Melbourne were invited to participate in the research project. Study approval from the Human Research Ethics Committee of Victoria University was obtained prior to recruitment.

The acceptance criterion for participation was two years minimum paddling and racing experience. A total of thirty-four paddlers met this criterion and agreed to participate in the study (eighteen male, sixteen female, average age 49.8 ± 14.6, body mass 73.6 ± 11.7 Kg). Written description of the project was provided to each participant and written consent was obtained from all participants prior to commencement of testing. Paddlers from three clubs participated in the project; seventeen from club A, thirteen from club B and four from club C.

The racing performance record of club A was superior to that of clubs B and C, and club B’s performance was superior to that of club C. To meet the team testing requirement paddlers from club C were combined with club B.

Skill is a continuum. As such, when studying performance on the basis of skill a decision has to be made on how to define groups for statistical comparisons. There has to be sufficient differences between the groups to enable statistical differentiation. To meet these conditions paddlers on an individual basis were classified as being more skilled if they had participated in a national or an international championship. All other paddlers were classified as being less skilled. However there are some issues to consider with this classification system. For example a more skilled paddler may have met the criteria because they were a member of a high performance crew or because they were selected for a state or a national team whilst they themselves were no more skilled then a paddler classified as being less skilled who did not have the same opportunities. Also it is possible to achieve high performance through raw power with limited skill. Skill alone does not guarantee high performance. Thus the interpretation of test results requires careful thought.

In a team context club A (team 1) was identified as the more successful racing crew because of their superior race record and the combined clubs (team 2) were identified as being the less successful crew. The more successful crew (team 1) had seventeen members (eight male, nine female) consisting of ten more skilled (six male, four female) and seven less skilled (two male, five female) paddlers. The less successful crew (team 2) also had seventeen paddlers (ten male, seven female) consisting of fourteen less skilled (seven male, seven female) and three more skilled paddlers (three males).

Due to the fact that testing of an individual dragon boat paddler can only take place in a team setting problems arise in grouping paddlers according to skill and in interpreting their test results. For example more skilled paddlers in this study will come from both the more successful and the less successful dragon boat crew. Thus the conditions under which they perform their tests will differ. As an example a less skilled paddler from the more successful boat crew is likely to be tested under higher boat speeds and greater stroke rates than the less skilled paddlers in the less successful boat crew. The stroke rate in a crew is set by the strokes in the first bench and not by the paddler under test. Careful thought and interpretation of results will be required as it is likely that some confounding issues will need to be considered.

3.3 Test equipment

To study the biomechanics of dragon boat paddling the kinetic and kinematic characteristics of the paddle produced by each participant needs to be measured and recorded under representative racing conditions in a standard IDBF boat. The equipment consists of a standard IDBF dragon boat, a strain-gauged paddle that measures the paddling forces, an electronic data collection system, a laptop that records the data and a desk that houses the laptop and the LED flashlights that enable synchronisation of the video and paddle force data. Power is supplied to the paddle via a USB port from the laptop. The force output from the strain-gauged paddle and the light-flash synchronisation signal are cabled to the analogue-to-digital converter module. These analogue signals are sampled and converted to digital form at 200 Hz by the analogue-to-digital converter that transmits the data via a USB bus to the laptop, where a custom LabVIEW program stores, time stamps and saves the data in a spreadsheet for subsequent analysis.

The mechanical design and construction of the strain-gauged paddle was carried out by the author. Electronic design and construction and the fitment of the strain gauges (in a full bridge configuration) were performed by Mr Robert Stokes of Victoria University. The LabVIEW program for the laptop data collection system was developed by Mr Ian

Fairweather of Victoria University.

Video recordings of paddle kinematics and paddlers actions were captured at high speed by a Sony HDR-HC7 video camera via its smooth slow recording function that allowed a 3 s video clip to be produced at 200 Hz for each paddler.

The test equipment is shown in action in Figure 3.3-1 below with the strain-gauged paddle (Fig 3.3-2) about to be plunged into the water. The analogue-to-digital converter shown in Figure 3.3-3 is on board the boat and connected to the laptop that is being operated by the tester who has just triggered the synchronising light flash.

Figure 3.3-1: Test equipment in action on a standard IDBF dragon boat.

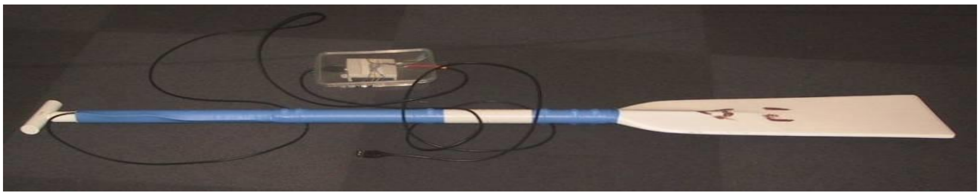

Figure 3.3-2: Strain gauged paddle with sensors and amplifiers housed in the paddle shaft.

Figure 3.3-3: Analogue to digital converter collecting data from strain gauged paddle.

3.4 Calibration

Table 3.4-1 lists the performance specification of the full bridge strain-gauged paddle (force transducer) used to test study participants. The transducer was designed to measure paddling forces to 500 N. Actual maximum paddle force measurements were generally in the 200 – 300 N range for participants but one male paddler did produce a maximum force of 460 N. Calibration was carried out with fixed standard weights (in 5 Kg increments to 40 Kg) applied at the mid-point of the paddle shaft (hand grip position) via a 100 mm wide loading strap. A water cushion to simulate field test conditions supported the paddle blade and a fixed point supported the handle (Figure 3.4-1). Calibration was completed prior to commencement of field testing of participants.

Table 3.4-1: Strain gauge paddle force transducer performance specification.

Design Load	500 N
Calibration Line Linearity R^2	0.997
Calibration Constant	7.16 mV/N
Measured Hysteresis	2.7 %
Measured Non-linearity	1.5 %
Average Repeatability	2.3 %
Average Noise Voltage	8 mV
Average Offset Voltage Drift	24 mV

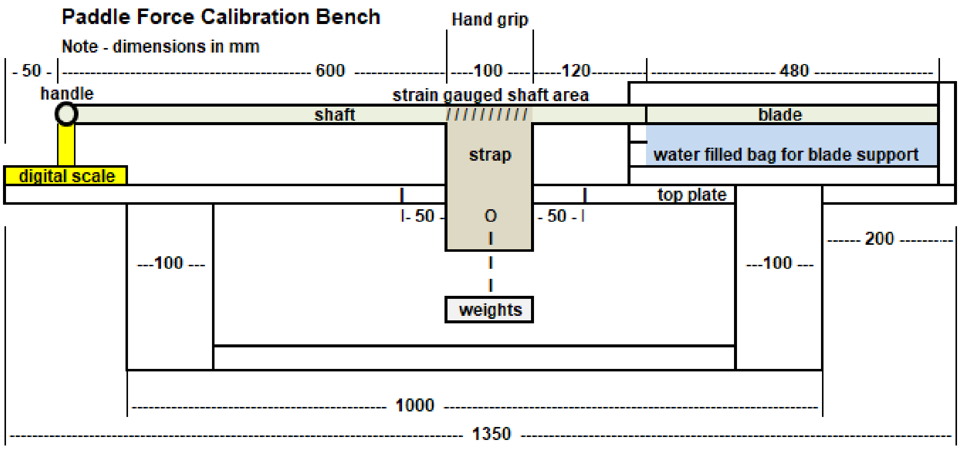

Figure 3.4-1: Paddle force calibration bench with static weights as test loads.

The paddle transducer output voltage was measured with increasing load from no load to maximum and then from maximum with decreasing load to zero load condition. Figure 3.4-2 shows the result of these measurements and the resulting hysteresis (calculated to be 2.7 %). A calibration line (R^2 = 0.977) was fitted to the measured data (Figure 3.4-3) and from it a calibration constant of 7.16 mV/N was calculated.

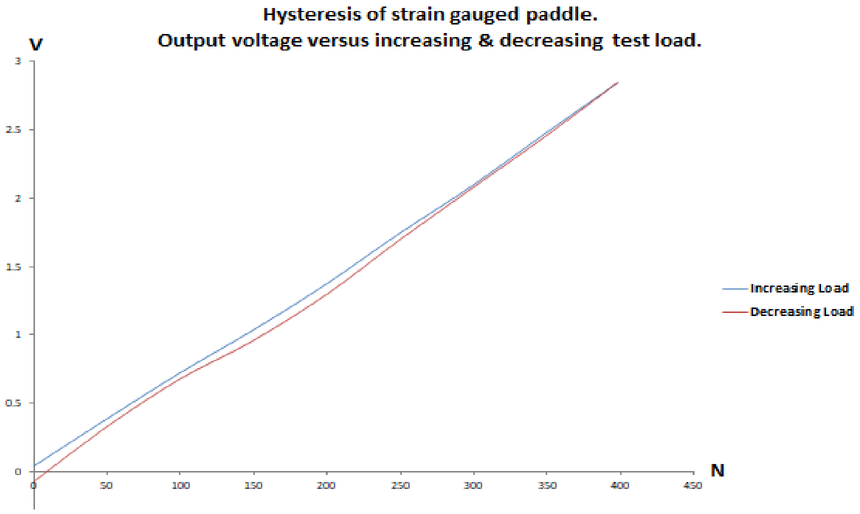

Figure 3.4-2: Transducer hysteresis curve with increasing and decreasing load.

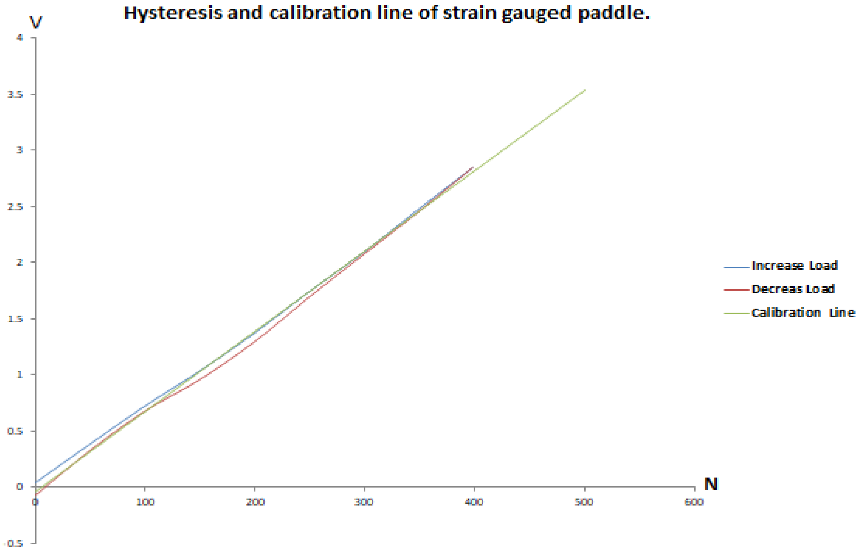

Figure 3.4-3: Transducer calibration line and hysteresis voltage versus load curve.

Repeatability (2.3 %) was assessed by manually cycling each test load three times on and off holding the load for five seconds in each position, recording and averaging the result for each five second period, and then averaging the results as a percentage of the test load. Non-linearity (1.5 %) of the increasing load curve was calculated as the maximum deviation relative to the calibration line. The average noise voltage for all load conditions was measured at 8 mV (equivalent to 1.1 N) and the average offset voltage drift from the start of a test run to the end of the run was 24 mV (3.4 N). Hence the force measurement error was estimated to be within ± 3.6 N. During testing of participants the voltage output of the strain-gauged paddle was recorded at 200 Hz and the associated paddle forces were calculated from the calibration constant and the offset voltage of each test run.

3.5 Synchronisation

The kinetic and kinematic data were both recorded at 200 Hz. Synchronisation between the force and video data was achieved via an LED light flash and its trigger signal that was recorded by the video and the force data collection system (Figure 3.5-1).

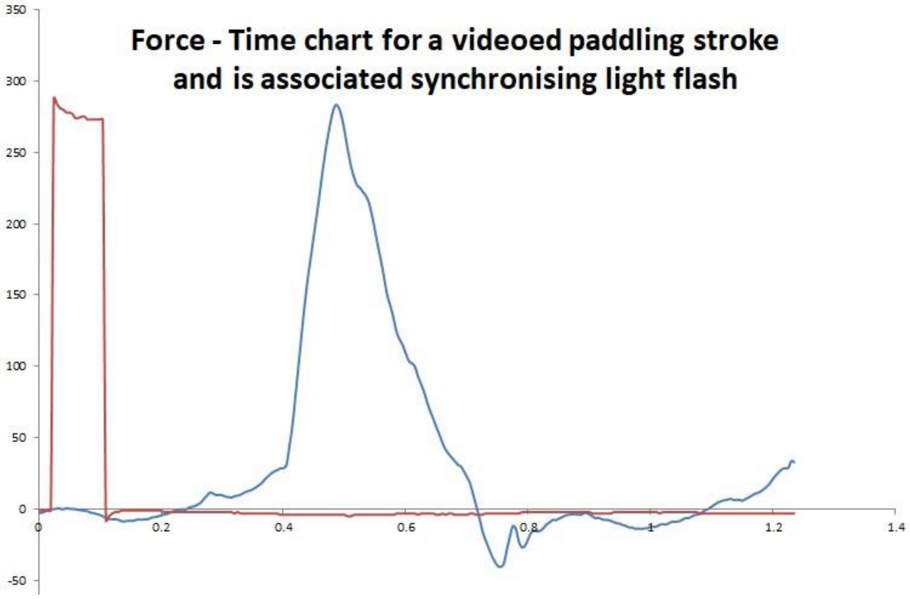

Figure 3.5-1: Force-Time chart for a videoed racing paddling stroke and synchronising light flash for a more skilled male test participant.

The principle of synchronisation via a light flash is illustrated in Figure 3.5-1. The video frame in which the light signal first appeared is aligned with its trigger signal recorded with the force data to locate the paddling force curve associated with the videoed paddling stroke. For the kinetic data time is referenced relative to the leading or trailing edge of the light flash trigger signal and for kinematic data relative to the video frame in which the light flash first appears or is extinguished. Temporal alignment between the force and video data is thus achieved in an objective manner to an accuracy of 0.005 s.

3.6 Testing

Data from the two teams were collected in two sessions over a weekend on their normal training days one month prior to the start of the racing season. Team 2 (the less successful racing crew) was tested on the first day and team 1 (the more successful racing crew) was tested on the following day. Weather conditions on both days were very similar.

Each paddler performed a 30 s maximum effort paddling test in a team setting with the strain gauged paddle during a simulated dragon boat race whilst seated in their preferred seating position. During each test run the force data were continuously recorded at 200 Hz by the data collection system. At the end of the test run a minimum of two minutes rest between each test was allowed for recovery.

Kinematic data for one paddling stroke for each paddler were recorded by a stationary video camera (Sony HDR-HC7) operating at 200 Hz during a 3 s video clip. A high speed stationary camera was necessary to observe in detail the paddle-water interaction during the paddling stroke via a stationary reference frame. Distance calibration was made possible by taped marked points locating each seat bench on each side of the boat. These taped marks provided reference lengths for video analysis.

From visual and temporal observations at local regattas it was established that local dragon boat crews raced at an average boat speed of 3.0-3.5 m/s with an average displacement of 3.0-3.3 m per paddling stroke. Thus the field of view was set at 6 m (giving a resolution of approximately 0.01m) to ensure that at least one full paddling stroke for each paddler was recorded. The average boat speeds implied that a dragon boat would cover a distance of 9.0-11.5 m in the available 3s time for high speed recording. Since the length of a dragon boat is 12.4 m and the spacing of the 10 seats is 0.8 m it was important to initiate high speed recording only when the bow of the boat was clearly visible in the centre of the camera's viewing screen. This was necessary to ensure the recording of a full paddling stroke for paddlers sitting in the rear seats of the boat.

Test runs were set at approximately 100 m to ensure maximum boat speed in front of the camera. The field of view of the camera was centred on a reference buoy positioned approximately 20 m from the camera. Each test run was in the opposite direction to the previous one to ensure video coverage of both sides of the boat. The sweeps were instructed to keep their boat running parallel to shore and to maintain a distance of approximately 2 m from the reference buoy. Figure 3.6-1 shows the schematic diagram of the test layout.

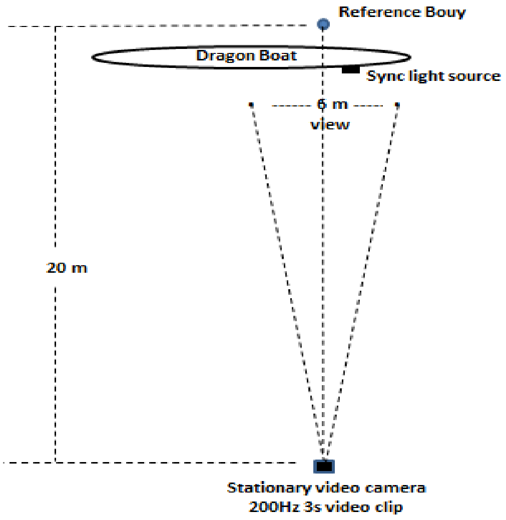

Figure 3.6-1: Schematic layout for video recording of a racing paddling stroke.

3.7 Theoretical model of the dragon boat paddling stroke

Chow & Knudson (2011) recommend the use of deterministic models to help identify meaningful dependent variables in biomechanics research. However Lees (2002) warns that in doing so, technique variables are often overlooked. For dragon boat paddling or canoeing there are no deterministic models. However two deterministic models have been developed for kayaking (McDonnell, et al., 2012; Wainwright, at al., (2015) and one for rowing (Soper & Hume, 2004). These models are complex and multi-level. They aim to provide broad information showing all factors that affect performance. However such broad views are of limited use to coaches in helping paddlers improve performance. They do not address the basic issues of paddling technique. How the paddler moves and what the paddler does during movement For example McDonnell, et al., (2013) found in their study that stroke displacement and stroke time determine average kayak velocity. In their conclusion they recommended that coaches focus interventions on increasing stroke rate while maintaining stroke displacement. This is a simplistic view that ignores paddling technique. Wainwright, et al., (2015) in their study of kayaking provided a complex deterministic model with much detail but no guidance for practitioners of the sport. Their key finding that propulsive impulse had the largest influence on kayak velocity raises the question of how does paddling technique affect propulsive impulse. Issues of technique are not explored in these models.

Authors involved in working with athletes such as Plagenhoef (1979) and Sperlich &Baker (2002), and researchers like Court et al., (1980) and Rottenbacher et al., (2011, 2015) use practical methods to study technique and provide biomechanical data that can help paddlers improve performance. Plagenhoef (1979) abandoned using complex computer analysis of kinematic and kinetic data on body segments in studying paddling technique as this approach was found to be of little help to paddlers. He settled on methods based on ease of doing the work and on whether the information could and would be used; whether coaches and paddlers could understand the information and apply it.

Sperlich &Baker (2002) and Rottenbacher et al., (2011; 2015) reviewed the process of biomechanical testing in elite canoeing. For them on-water force measurement on the paddle is the main method. This allows athletes to be compared, norms to be established and training to be monitored. The shape of the force-time curve indicates paddling technique and enables faults to be detected and corrected. Combined with video an overlaid force-time curve enables deeper analysis and qualitative aspects of technique to be addressed.

The author of this thesis adopts a similar view and used an engineering approach to develop a theoretical model for dragon boat paddling centred on the force time curve of the paddling stroke, key paddle events and the action phases of the paddling stroke. Kinetic and kinematic parameters of performance are then derived from the model for testing and analysis. The kinetic variables are impulse, force and force rate, and the kinematic variables are angle, position and velocity, within each action phases of the paddling stroke mapped onto the force time curve. This ensures that technique variables are not overlooked.

In this thesis the aim is to gain an understanding of the biomechanics of dragon boat paddling by examining the kinetic, kinematic and temporal interaction of the paddle with respect to the water for a single paddling stroke performed under racing conditions. Thus the force-time curve, key events and action phases of the paddling stroke are the focus of research.

Figure 3.7-1 shows these key events and action phases of a racing paddling stroke for a more skilled male test participant.

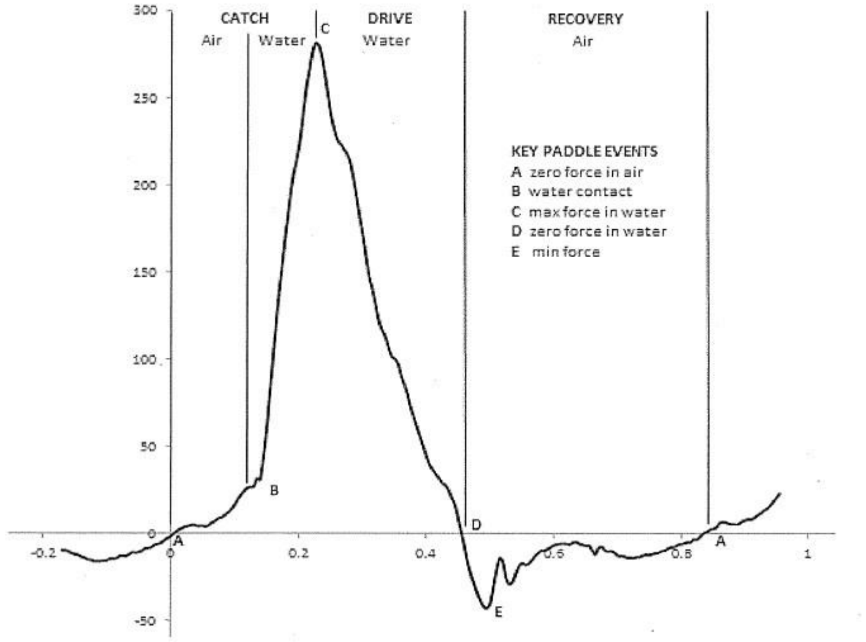

Figure 3.7-1: Key paddle events and phases of a dragon boat paddling stroke.

The paddling stroke consists of three action phases; catch, drive and recovery. Each phase is bound by key events. The catch phase has an air and water component. It begins with the set-up position in air (point A) when the paddle force is zero, continues to the point of water contact (point B) and concludes at the point in time when the paddle force is maximum (point C). The drive phase commences at the end of the catch (point C, maximum paddle force) and concludes when the paddle force in water is zero (point D). Recovery starts at the end of the drive phase (point D) with zero force in water followed by water exit and the paddle travelling in the opposite direction in air to that in water. It moves through the point of maximum acceleration (point E) to the paddle set-up position (point A) and the paddling cycle recommences. Point E may be in water if the exit is poor and blade drag is produced or in air if the exit is good and the paddle is accelerated quickly to the set-up position.

The potential variables of interest specified by the theoretical model of dragon boat paddling include the impulse, maximum and average force, rate of change of force, time ratios, paddle positions, angles and velocities, and angular rates of change of the paddle for the three phases of the paddling stroke (catch, drive and recovery).

Kinematic data measurements of the paddle are made using the reference frame (X-Y plane) defined by the stationary video camera and the videoed frames of the paddling stroke. The initial water surface contact point of the paddle blade defines the horizontal plane (and X axis), from which vertical points of paddle motion are measured. . Horizontal points of paddle motion are measured relative to vertical plane (and Y axis) defined by the black-white tape line on the side of the boat marking the front edge of the paddler’s seat. Paddle angles are measure relative to the vertical Y axis counter clockwise in the positive direction. Time is measure via frame count relative to the light flash. At 200 Hz each frame represents a time of 0.005 s. This reference frame for kinematic measurements is shown in Figure 3.7-2.

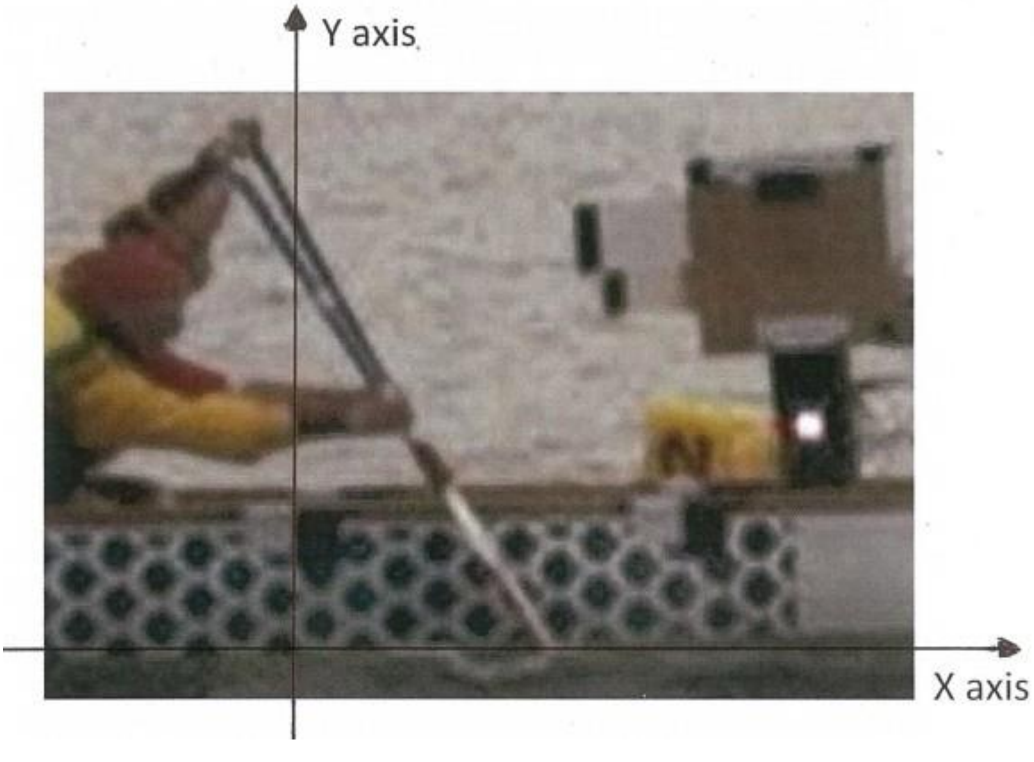

Figure 3.7-2: Reference frame for measuring the kinematic parameters of the paddle.

Screenshots of video frames illustrating the key kinetic and kinematic events of the theoretical model for the water phase of the paddling stroke is shown for a test subject in Figure 3.7-3. The test subject is a more skilled male paddler seated third from the front on the right hand side of the boat and is wearing a white cap. Frame A of Figure 3.7-3 shows the point in time when the paddle blade tip makes contact with the water surface. The paddle force is at maximum in Frame B with the paddle at a positive angle prior to the vertical position. The vertical paddle position is shown in Frame C. The paddle position at the time of zero force in water is shown in Frame D. Paddle exit from the water is shown in Frame E. In the screenshots the initial water contact point (stationary reference point) is located above the letter ‘I’ shown under each screenshot of Figure 3.7-3.

Frame A – Paddle water contact

I reference point ‘water contact’

Frame B - Max force in water

I reference point ‘water contact’

Frame C - Vertical paddle position

I reference point ‘water contact’

Frame D - Zero force in water

I reference point ‘water contact’

Frame E – Paddle water exit

I reference point ‘water contact’

Figure 3.7-3: Screenshots of video frames for key paddle kinetic and kinematic events relative to the initial paddle blade water contact point (reference point) for a more skilled male paddler (sitting third from front on RHS wearing a white cap).

The key events, namely water contact, maximum paddle force in water, vertical paddle position, zero paddle force in water and paddle exit, shown in the screenshots of Figure 3.7-3 correspond with the key events shown in Table 3.7-1. Time, video frame number, paddle force and status of light source are shown in relation to the paddle key events.

Table 3.7-1: Extracts from the kinetic data analysis spreadsheet of the more skilled male paddler whose data was used in Figure 3.5-1, Figure 3.7-1 and Figure 3.7-3 with the key events in the screenshots of Figure 3.7-3 corresponding with the key events of this table.

Time, s	Video Frame No	Paddle Force, N	Light	Key Events
-0.140	-1	-5.0	1	
-0.135	1	-6.0	0	Sync Light Off
-0.130	2	-6.9	0	
-0.005	27	-0.3	0	
0	28	1.0	0	Zero paddle force in air
0.005	29	1.6	0	
0.140	56	26.4	0	
0.145	57	27.4	0	Paddle blade water contact
0.150	58	28.5	0	
0.235	75	277.1	0	
0.240	76	283.1	0	Maximum paddle force in water
0.245	77	281.7	0	
0.270	82	233.1	0	
0.275	83	227.3	0	Paddle in vertical position
0.280	84	225.1	0	
0.465	121	10.5	0	
0.470	122	2.4	0	Zero paddle force in water
0.475	123	-5.8	0	
0.550	138	-25.4	0	
0.555	139	-20.9	0	Paddle blade exit from water
0.560	140	-16.4	0	

3.8 Paddle path in water and the associated paddle forces

Plagenhoef stated that for an efficient paddling stroke the paddle ‘blade is actually stationary in the water’ (Plagenhoef, 1979, p456). By this he meant that the paddle blade enters and leaves the water at the same spatial location, that is, at the initial paddle blade water contact point. He concluded that the absolute motion of the paddle blade in the water is sufficient on its own to differentiate good paddlers from poor paddlers – no other information is required (Plagenhoef, 1979, p459). Based on these finding the paddle path in water for a good (more skilled) paddler can be constructed.

Figure 3.8-1 shows the paddle path during water entry, that is, during the water component of the catch phase of the paddling stroke for a good (more skilled) female paddler. As can be seen the paddle blade moves vertically down into the water as it rotates producing a variable angle of attack and a variable area of water contact.

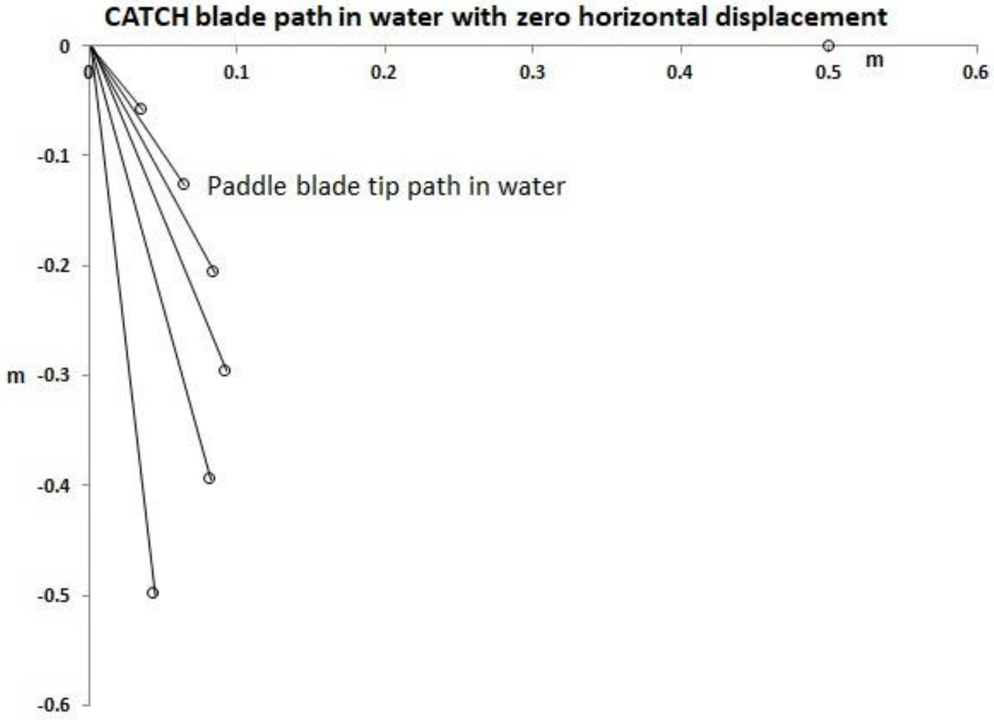

Figure 3.8-1: Paddle blade tip path during the catch phase of a paddling stroke with zero horizontal paddle displacement for a good (more skilled) female paddler.

A strain gauged paddle measures the force that is perpendicular to the blade surface. The propulsive force generated by a paddle acts through the body of the paddler to propel the boat forward. This propulsive paddle force can be resolved into lift and drag force components. A force that acts perpendicular to the direction of motion in a fluid is by definition a lift force whilst a force that acts in the direction of motion is called a drag force. Due to the angular orientation of the paddle blade and the direction of paddle motion during the catch (Figure 3.8-1), the propulsive force pushing the boat forward is a lift force that closely tracks the normal blade force. This fact is clearly shown in Figure 3.8-2 and hence it can be said that boat propulsion during the catch phase of the paddling stroke is based on lift forces.

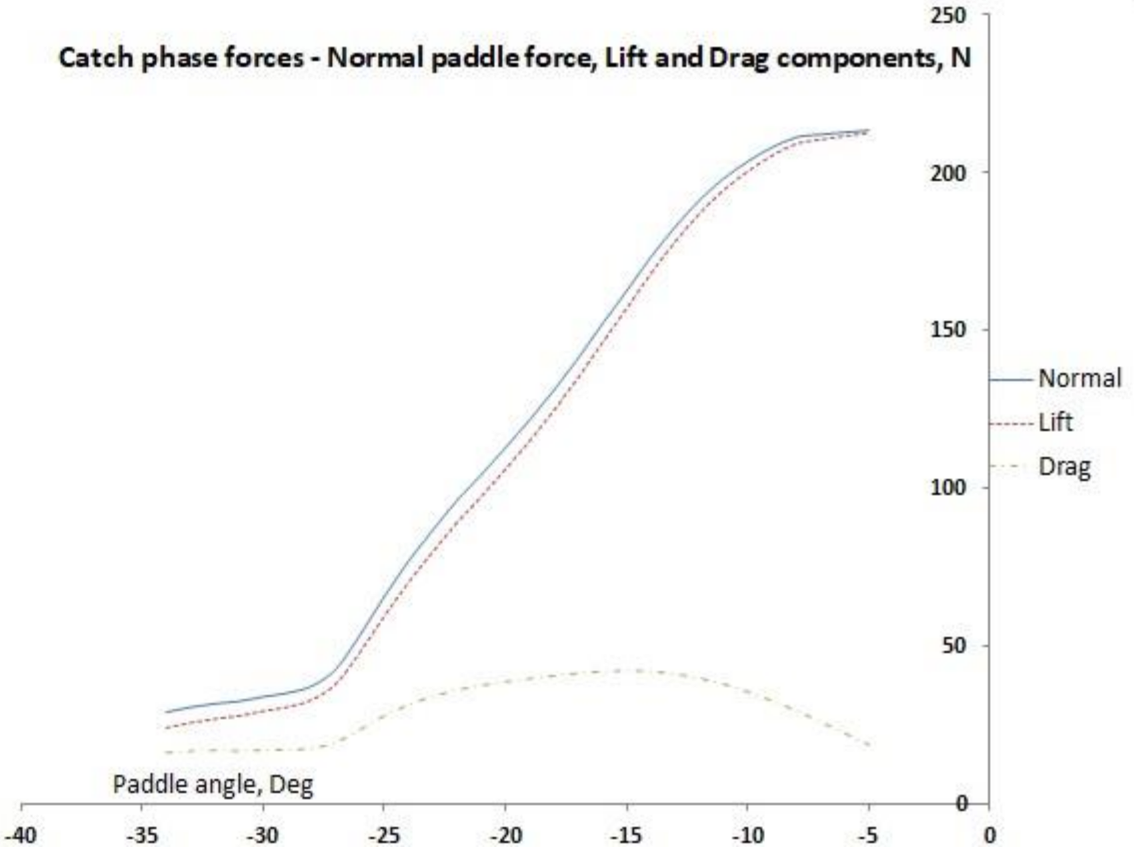

Figure 3.8-2: Normal, lift and drag forces acting on the paddle blade during the catch phase of a paddling stroke with zero horizontal paddle displacement for a good (more skilled) female paddler.

At the end of the catch phase of the paddling stroke full blade immersion is reached and the drive phase of the paddling stroke begins. The vertical linear motion of the paddle ceases but the rotation of the blade continues. The centre of rotation remains fixed on the water surface at the point of initial water contact. Rotation of the blade continues until the paddle exit point is reached and the withdrawal process of the blade from the water begins. Figure 3.8-3 shows the paddle path during the drive phase of a paddling stroke for a good (more skilled) female paddler.

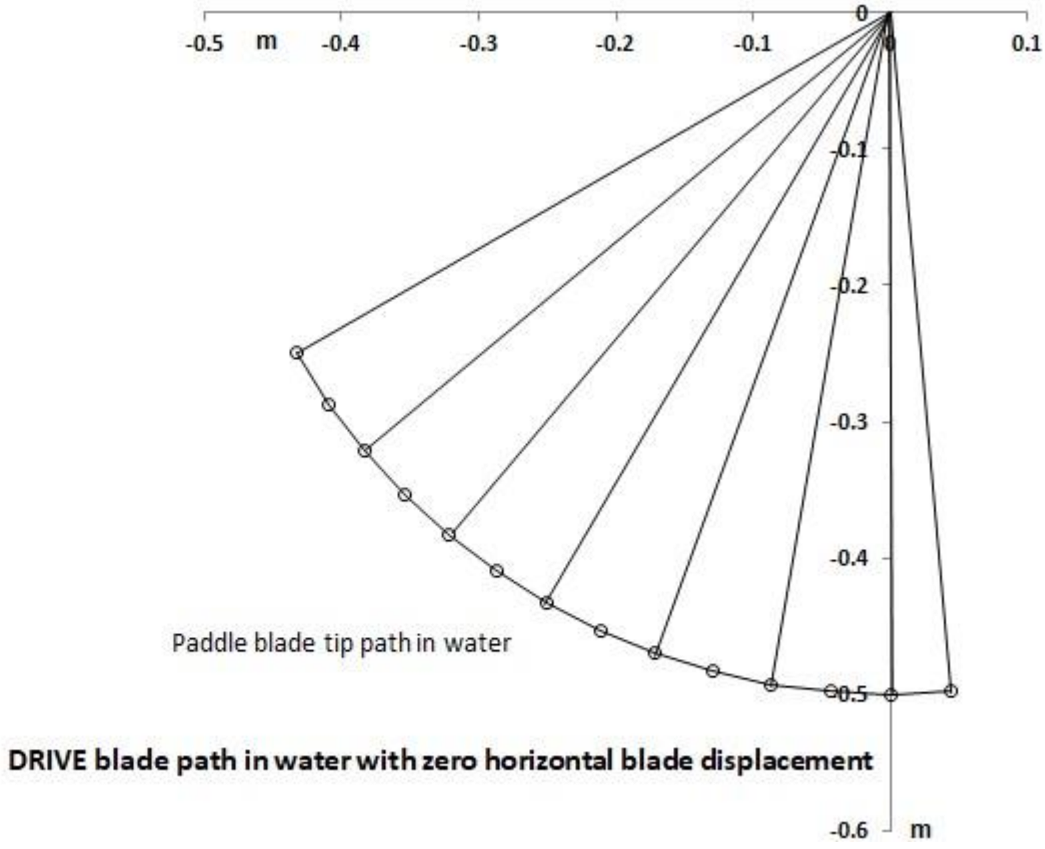

Figure 3.8-3: Paddle blade tip path during the drive phase of a paddling stroke with zero horizontal paddle displacement for a good (more skilled) female paddler.

The paddle blade in effect is basically a flat plate. During the drive phase of the paddling stroke the blade produces a rotational drag force (a force that is normal to the rotating blade surface) that can be resolved into horizontal drag and vertical lift forces. The resolved lift and drag forces of the drive phase together with the rotational drag force (normal force) of the blade are shown in Figure 3.8-4 as a function of paddle angle measured relative to the vertical axis, for a good (more skilled) female paddler. As can be seen the resolved horizontal drag force closely tracks the normal force on the paddle blade. Thus it can be said that during the drive phase of the paddling stroke boat propulsion is based on drag forces.

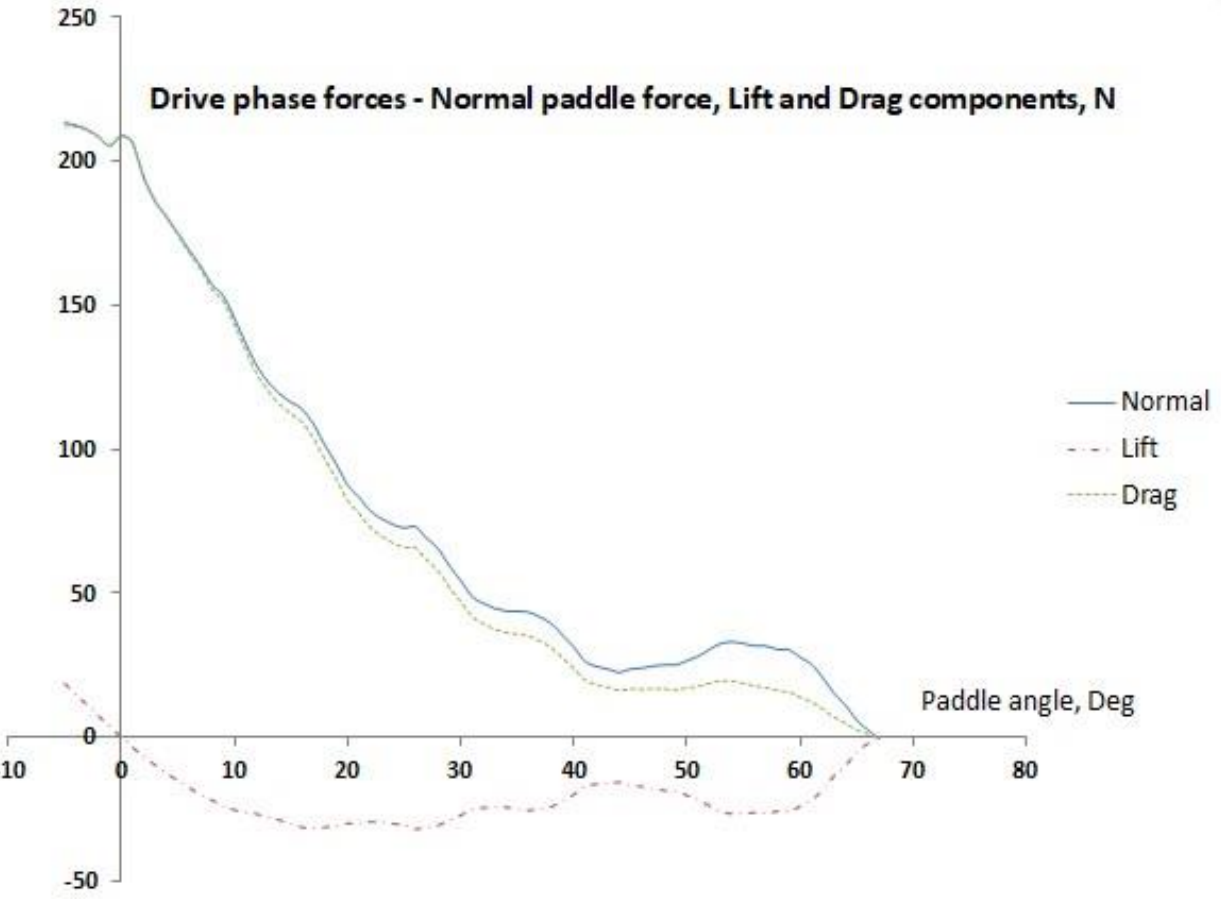

Figure 3.8-4: Normal, lift and drag forces acting on the paddle blade during the drive phase of a dragon boat paddling stroke with zero horizontal paddle displacement for a good (more skilled) female paddler.

The paddle blade motion in water for the catch and drive phases of the paddling stroke, together with the motion of the paddle shaft and handle in air, are shown in Figure 3.8-5 for a good (more skilled) female paddler. Line AE represents the paddle at water contact. Path AB is the top hand path in air whilst path EF is the blade tip path in water during the catch phase of the paddling stroke. Line BF represents the paddle at full blade immersion. Path BC is the top hand path in air and path FG is the blade tip path in water during the drive phase of the paddling stroke. Path CD is the top hand path in air and path GE is the blade tip path in water during paddle exit from the water. Together these statements detail the motion of the paddle during the propulsive phase of the paddling stroke.

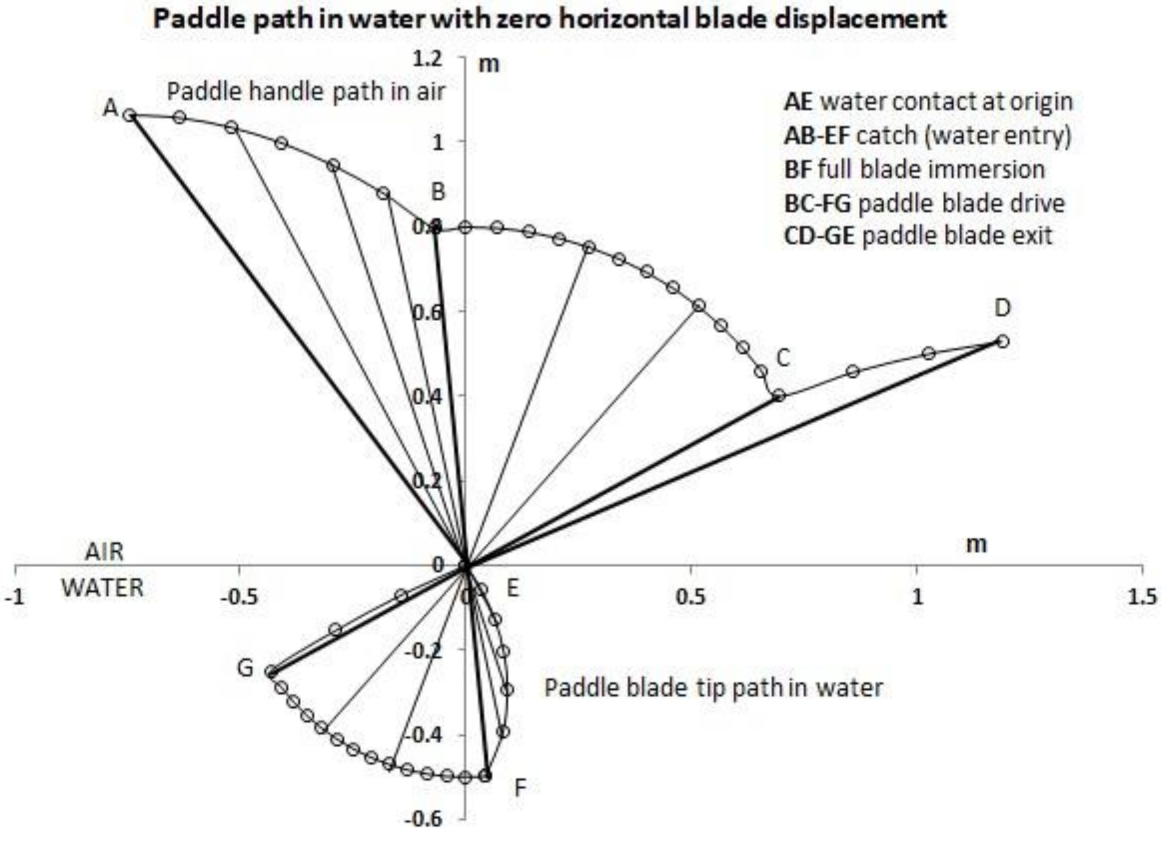

Figure 3.8-5: Paddle path during the water phase of a dragon boat paddling stroke with zero horizontal paddle displacement for a good (more skilled) female paddler.

The force normal to the paddle blade during the catch and drive phases of a paddling stroke with zero horizontal paddle displacement, together with the horizontal and vertical components of the force transmitted to the boat by the body of the paddler, are shown in Figure 3.8-6 as a function of paddle angle for a good (more skilled) female paddler. During the catch phase of the paddling stroke the lift forces on the blade produce the horizontal propulsive forces acting on the boat whilst the drag forces on the blade reduce the vertical gravitational force imposed on the boat. For the drive phase of the paddling stroke it is the drag forces on the blade that produce horizontal propulsive forces whilst the lift forces on the blade increase the vertical forces imposed on the boat. From Figure 3.8-6 it can be seen that the propulsive horizontal boat forces track the normal blade forces closely throughout the water phase of the paddling stroke.

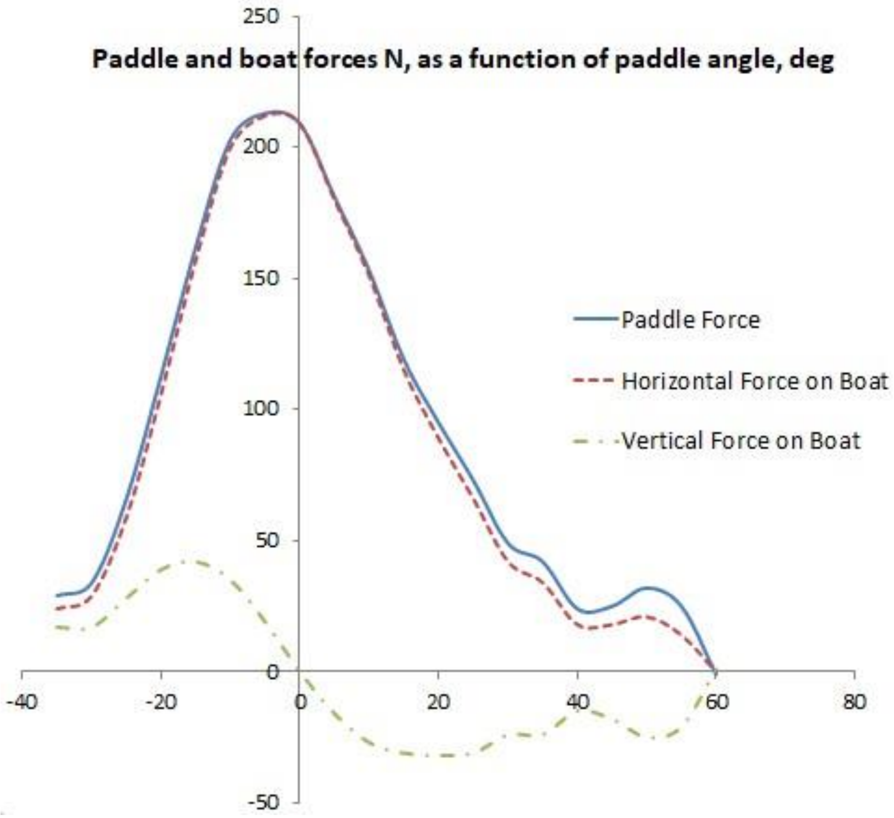

Figure 3.8-6: Paddle force normal to the blade during a dragon boat paddling stroke with zero horizontal paddle displacement, and, the horizontal and vertical forces acting on the boat as a function of paddle angle, for a good (more skilled) female paddler.

Extracts from the data file used to construct the force-angle diagrams of Figures 3.8-2, 3.8-4 and 3.8-6 are shown in Table 3.8-1. The table provides additional information with respect to the paddling stroke. It lists the forces measured by the strain gauged paddle, the paddle angles obtained from the video analysis, key paddle events occurring during the paddling stroke, phases of the paddling stroke, type of paddle propulsion and, the horizontal and vertical forces transmitted to the boat by the paddler as a function of stroke time.

Table 3.8-1: Paddle force, angle, key event, stroke phase, propulsion type and boat forces as a function of time during the water phase of a dragon boat paddling stroke with zero horizontal paddle displacement for a good (more skilled) female paddler.

Stroke Time, s	Paddle Force, N	Paddle Angle, deg	Key Paddle Events	Stroke Phase	Type of Propulsion	Horizontal Boat Force, N	Vertical Boat Force, N
0	29	-35	Water contact	catch	Lift	24	17
0.02	34	-30		catch	Lift	29	17
0.045	66	-25		catch	Lift	59	28
0.07	113	-20		catch	Lift	106	39
0.095	162	-15		catch	Lift	157	42
0.120	203	-10		catch	Lift	200	35
0.145	213	-5	Max Force	catch	Lift	212	19
0.170	205	0		drive	Drag	205	0
0.195	181	5		drive	Drag	180	-16
0.220	153	10		drive	Drag	151	-27
0.245	119	15		drive	Drag	115	-31
0.270	95	20		drive	Drag	89	-32
0.300	73	25		drive	Drag	66	-31
0.330	49	30		drive	Drag	42	-24
0.360	42	35		drive	Drag	34	-24
0.390	24	40		drive	Drag	18	-15
0.420	25	45		drive	Drag	18	-18
0.450	32	50		drive	Drag	21	-25
0.480	25	55		drive	Drag	14	-21
0.510	-1	60	Zero Force	drive	Drag	0	1

3.9 Definitions of terms

Potential variables of interest derived from the theoretical model of dragon boat paddling described in the previous sections and their associated terms are defined and shown in Table 3.9-1 below.

Table 3.9-1: Definitions of potential test parameters and associated terms.

Terms	Units	Definitions
Air time	s	The time during which the paddle blade is in the air for a paddling stroke. It is the time from the end of paddle exit when the paddle blade is fully out of the water to the time of water contact when the paddle blade tip contacts water.
Blade forward reach (Reach water contact)	m	The horizontal distance from the front edge of a paddler's seat to the water contact point of their paddle blade during the catch phase of the paddling stroke.
Blade displacement on water surface	m	The horizontal distance on the water surface between the water contact point and water exit point of the paddle blade for a paddling stroke.
Boat displacement per stroke	m	The horizontal distance moved by the boat during a paddling stroke.
Boat velocity average	m/s	The average speed of a boat during a paddling stroke.
Boat velocity during propulsion	m/s	The average speed of a boat during the time the paddle is in the water for a paddling stroke.
Catch		The part of a paddling stroke that starts with the paddle in the set-up position in air and ends when the paddle blade force in water is the maximum. It is the period between zero force on the paddle in air and maximum force on the

		paddle in water. When only kinematic data are available it is the period between the time when the top hand of the paddler (paddle handle) in air is at maximum vertical height, and the time of full blade immersion in water.
(air component)		The part of a paddling stroke that starts with the paddle in the set-up position in air and ends when the paddle blade contacts water.
(water component)		The part of a paddling stroke that starts with water contact and ends at maximum paddle force (when force data is available) or full blade immersion (when only kinematic data is available).
Catch velocity average in air	m/s	The average vertical velocity of the paddle from the set-up position to its height at the time of water contact of the paddle blade measured via the paddle handle positions.
Drive		The part of a paddling stroke that starts at the end of the catch phase of the paddling stroke when the paddle blade force is at its maximum value and ends when the force on the paddle in water is zero. When only kinematic data are available it is the part of the paddling stroke from full blade immersion to commencement of paddle exit (beginning of blade extraction) from the water.
Exit		The part of a paddling stroke that starts when the force on the paddle in water is zero and ends when the paddle

		blade is fully exposed to the air. When only kinetic data is available it is approximated by the point in time when the force on the paddle in water is zero. When only kinematic data are available it is the part of the stroke when the paddle starts to move out of the water and ends when the paddle blade is fully in the air.
Force average catch	N	The average force on the paddle during the catch phase of the paddling stroke.
Force average drive	N	The average force on the paddle during the drive phase of the paddling stroke.
Force fall time	s	The time interval used to calculate the rate of force decline to zero at the end of the drive phase of the paddling stroke. It is the time taken for the force on the paddle to fall from 20 percent of the maximum value to zero force in water. Note: See force rate reduction for further information.
Force paddle water contact	N	The force on the paddle when the blade tip contacts water. When only force data is available it is approximated by 15 percent of the maximum paddle force.
Force paddle maximum	N	The maximum force on the paddle during the water phase of the paddling stroke.
Force paddle minimum	N	The maximum negative force on the paddle during the recovery (air) phase of the paddling stroke. This negative force is due to the forward inertial acceleration of the

		paddle which causes the paddle shaft to bend in the opposite direction to that when the paddle blade is in the water under a propulsive load.
Force paddle propulsive	N	The average force on the paddle during the water phase of the paddling stroke.
Force paddle vertical	N	The force on the paddle at the time when the paddle shaft is in the vertical position.
Force quality drive	ratio	The ratio of the average drive force to the maximum force on the paddle during the drive phase of the paddling stroke (mean to peak force ratio).
Force quality propulsive	ratio	The ratio of the average force to the maximum force on the paddle during the water phase of a paddling stroke.
Force rate of development	N/s	The average slope of the straight line from 20 percent of maximum force to 80 percent of maximum force during the catch phase of a paddling stroke. This range is different to the 10 to 90 percent range chosen by Ho et al (2009) [S. Ho, personal communication, July 12, 2012)]. The reason for the reduced range is the non-linear nature of the force-time curve below the 20 percent and above the 80 percent regions of the catch force-time curve.
Force rate of reduction	N/s	The average slope of the straight line at the end of the drive phase of the paddling stroke from 20 percent of maximum force to zero force on the paddle in water. The reason for selecting this time range is that for some

		paddlers the shape of the force-time curve is non-linear above that region due to their paddle exit technique.
Force rise time	s	The time interval used to calculate the rate of force rate increase on the paddle during the catch phase of a paddling stroke (the time taken for the force on the paddle to rise from 20 to 80 percent of the maximum force). The reason for the reduced range is the non-linear nature of the force-time curve below the 20 percent and above the 80 percent regions of the catch force-time curve.
Key kinematic paddle events		Important kinematic paddle evens that are used to describe a paddling stroke: paddle set-up position, water contact, vertical paddle position and water exit.
Key kinetic paddle events		Important kinetic paddle events that are used to describe a paddling stroke: maximum force, minimum force, zero force in water, zero force in air.
Paddle angle water contact	deg	The angle of the paddle relative to the vertical at the time of water contact.
Paddle angle maximum force	deg	The angle of the paddle relative to the vertical at the time of maximum paddle force in water.
Paddle angle zero force in water	deg	The angle of the paddle relative to the vertical at the time of zero paddle force in water.
Paddle angle water exit	deg	The angle of the paddle relative to the vertical at the instance of time when the paddle blade tip leaves the water.
Paddle angle minimum force	deg	The angle of the paddle relative to the vertical at the time

		of maximum negative force on the paddle in air (during the recovery phase of a paddling stroke).
Paddle angle zero force air	deg	The angle of the paddle relative to the vertical at the time of zero paddle force in air.
Paddle angular velocity in water	deg/s	The average rate of angular rotation of the paddle during the water phase of the paddling stroke.
Paddle set-up	m	The point in time in air at the end of the recovery phase of a paddling stroke from which the catch phase of the stroke begins. It is the point in time when the paddle force in air is zero. When only kinematic data are available it is the point in time when the top hand of the paddler (paddle handle) is at maximum vertical height.
Paddle stroke length	m	The length of the paddling stroke from the point of water contact to the point of water exit measured relative to the boat on a horizontal line parallel to the water surface.
Propulsion		Paddle-water interaction that produces boat motion.
Propulsion time		The time from paddle blade water contact to the time of zero paddle force in water.
Race stroke		A paddling stroke made at a time when the boat is travelling at racing speed.
Reach water contact (Blade forward reach)	m	The horizontal distance from the front edge of a paddler's seat to the water contact point of the paddle blade during the catch phase of their paddling stroke.
Recovery		The exit and air phase of the paddling stroke that culminates in the paddle set-up position. It is the part of the paddling stroke that starts with the paddle force of

		zero in water and ends with the paddle force of zero in air. When only kinematic data are available it is the part of the paddling stroke that starts with the commencement of blade extraction from the water and ends when the paddle is in the set-up position with the top hand of the paddler (paddle handle) at maximum vertical height.
Start stroke		The first stroke of a race that commences boat motion. It usually begins with the paddle blade fully immersed in water but may begin in the air or with partial immersion.
Stroke impulse catch	N.s	The area under the force-time curve for the catch phase of the paddling stroke. It has two components; an air and a water component.
(in air – not propulsive)		For the air component it is the area under force-time curve from the time of zero force on the paddle in air to the time of water contact.
(in water - propulsive)		For the water component it is propulsive and is the area under force-time curve from the time of water contact to the time of maximum force on the paddle in water.
Stroke impulse drive	N.s	The area under the force-time curve for the drive phase of the paddling stroke. It is the area under force-time curve from the time of maximum force on the paddle in water to the first time of occurrence of zero force on the paddle in water.
Stroke impulse drive rate	N.s/s	The product of drive phase impulse (N.s) and stroke rate (spm) for a paddling stroke divided by 60 and expressed as Newton seconds per second. It is used to normalise the

		drive impulse to the unit of time and thereby enable performance comparisons to be made between paddlers for the drive phase of the paddling stroke. (It is the average force held for one second that would produce an impulse equal to the drive phase impulse of the paddling stroke.)
Stroke impulse propulsive	N.s	The area under the force-time curve for the propulsive phase of the paddling stroke. It is the area under the force-time curve from the time of water contact to the first time of occurrence of zero force on the paddle in water.
Stroke impulse rate	N.s/s	The product of stroke impulse propulsive (N.s) and stroke rate (spm) for a paddling stroke divided by 60 and expressed as Newton seconds per second. It is used to normalise the stroke impulse propulsive to the unit of time and thereby enable performance comparisons to be made between paddlers. This term is equivalent to the average force per stroke but it is not equivalent to the average propulsive force measured by the strain gauged paddle during the stroke. Averaging the force over a paddling stroke using the stroke impulse rate concept takes account of both water and air time, which the measured force, does not. To avoid the confusion of having two average force measures (one for the water phase and the other for the paddling stroke) and to emphasise the importance of the two key parameters determining boat propulsion (stroke

		rate and stroke impulse) the author has chosen to use the term stroke impulse rate and the units of N.s/s for the average force per paddling stroke.
Stroke impulse recovery	N.s	The area under the force-time curve of the paddle from the first time occurrence of zero force on the paddle in water to the time of zero force on the paddle in air for a paddling stroke. The time period includes the paddle exit time and the air time of the paddle motion to the paddle set-up position. It is used to measure the smoothness of the recovery phase of the paddling stroke. Note: The magnitude of both positive and negative areas are added together to obtain this parameter.
Stroke rate	spm	The term used by paddlers and coaches to describe the rate of paddling action. It is the reciprocal of the stroke time expressed in terms of strokes per minute.
Stroke time	s	The period of time between water contact of one paddling stroke to water contact of the subsequent paddling stroke. When only force data are available stroke time is the time between the occurrences of the initial zero force events in water subsequent to the maximum force event occurring in consecutive paddling strokes.
Stroke time catch propulsive (water component)		The time duration of the water component of the catch phase of the paddling stroke (from water contact to maximum paddle force in water [full blade immersion]).
Stroke time drive		The time duration of the drive phase of the paddling

		stroke (from maximum paddle force to zero paddle force in water [start of paddle exit]).
Stroke time propulsive		The time duration of the propulsive water phase of the paddling stroke (from water contact to zero paddle force in water [start of paddle exit]).
Stroke time recovery		The time duration of the recovery phase of the paddling stroke (from zero paddle force in water [start of paddle exit] to zero paddle force in air [paddle set-up position]).
Stroke time propulsive ratio	ratio	The ratio of paddle propulsion time (water propulsion time) to the time duration of a paddling stroke.
Water contact		The event when the paddle blade tip in air contacts the water surface during the catch phase of the paddling stroke.
Water propulsion time	s	The time during which paddle propulsion occurs (from water contact to zero paddle force in water [start of paddle exit]).

3.10 Selection of test parameters

In this thesis the focus of research is on the kinetic, kinematic and temporal interaction of the paddle with the water during a paddling stroke. Test parameter selection was based on prior research, the theoretical model of dragon boat paddling developed in sections 3.7 and 3.8 of this chapter and the practical paddling and coaching experience of the author. Parameters selected by Ho, et al., (2009) for the paddle in their study were average propulsive force, drive to recovery time ratio, mean to peak force ratio, peak propulsive force, rate of force development, stroke impulse, stroke rate, paddle angle at water entry and paddle angle at water exit. Plagenhoef (1979) selected paddle entry and paddle exit angles; Sperlich &Baker (2002) selected peak force, stroke impulse, stroke rate, water to stroke time ratio and boat velocity. All these test parameters except for drive to recovery and water to stroke time ratio were selected for this thesis with additional test parameters derived from the theoretical model of the dragon boat paddling stroke.

The number of kinetic, kinematic and temporal variables is large but it is bounded by the paddling and coaching experience of the author and the literature. The selected test parameters from Table 3.10-1 are summarised and listed as follows.

Thirteen kinetic test parameters were selected for evaluation; force average catch (propulsive), force average drive, force paddle water contact, force paddle maximum, force paddle vertical, force paddle minimum, force quality drive, force rate of development, force rate of reduction, stroke impulse catch (propulsive), stroke impulse drive, stroke impulse drive rate and stroke impulse recovery.

Twelve kinematic test parameters were selected for evaluation; paddle blade forward reach, blade displacement at the water surface, boat displacement per stroke, boat velocity average, boat velocity during propulsion, paddle angle at water contact, paddle angle at maximum force, paddle angle at zero force in water, paddle angle at water exit, paddle angle at zero force in air, paddle angular velocity in water, paddle stroke length and paddle stroke rate.

Seven temporal test parameters; stroke rate, stroke time, stroke time catch propulsive, stroke time drive, stroke time propulsive, stroke time recovery and stroke time propulsive ratio were selected for evaluation.

The selected kinetic test parameters and their definitions are shown in Table 3.10-1 below.

Table 3.10-1: Definitions of selected kinetic test parameters used in thesis studies.

Terms	**Units**	**Definitions**
Force average catch (propulsive)	N	The average force on the paddle during the water component of the catch phase of the paddling stroke.
Force average drive	N	The average force on the paddle during the drive phase of the paddling stroke.
Force paddle water contact	N	The force on the paddle when the blade tip contacts water.
Force paddle maximum	N	The maximum force on the paddle during the water phase of the stroke.
Force paddle vertical	N	The force on the paddle at the time when the paddle shaft is in the vertical position.
Force paddle minimum	N	The maximum negative force on the paddle during the recovery (air) phase of the paddling stroke.
Force quality drive	ratio	The ratio of the average drive force to the maximum force on the paddle during the drive phase of the paddling stroke (mean to peak force ratio).
Force rate development	N/s	The average slope of the straight line from 20 percent of maximum force to 80 percent of maximum force during the catch phase of a paddling stroke. The reason for selecting this range is the non-linear nature of the force-time curve below the 20 percent and above the 80 percent

		regions of the catch force-time curve.
Force rate reduction	N/s	The average slope of the straight line at the end of the drive phase of the paddling stroke from 20 percent of maximum force to zero force on the paddle in water. The reason for selecting this time range is that for some paddlers the force-time curve is non-linear above that region due to their paddle exit technique.
Stroke impulse catch (propulsive)	N.s	Area under the force-time curve for the water component of the catch phase of the paddling stroke. It is the area under force-time curve from the time of water contact to the time of maximum force on the paddle in water.
Stroke impulse drive	N.s	The area under the force-time curve for the drive phase of the paddling stroke. It is the area under force-time curve from the time of maximum force on the paddle in water to the first time of occurrence of zero force on the paddle in water.
Stroke impulse drive rate	N.s/s	The product of drive phase impulse (N.s) and stroke rate (spm) for a paddling stroke divided by 60 and expressed as Newton seconds per second. It is used to normalise the drive impulse to the unit of time and thereby enable performance comparisons to be made between paddlers for the drive phase of the paddling stroke. (It is the average force held for one second that would produce an impulse equal to the drive phase impulse of the paddling stroke.

Stroke impulse recovery	N.s	The area under the force-time curve of the paddle from the first time occurrence of zero force on the paddle in water to the time of zero force on the paddle in air for a paddling stroke. The time period includes the paddle exit time and the air time of the paddle motion to the paddle set-up position. It is used to measure the smoothness of the recovery phase of the paddling stroke. Note: The magnitude of both positive and negative areas are added together to obtain this parameter.
Time propulsion to recovery	ratio	The ratio of paddle propulsion time to paddle recovery time during a paddling stroke. The ratio of the time from paddle water contact to zero paddle force in water to the time from zero paddle force in water to paddle water contact.

The selected kinematic test parameters and their definitions are shown in Table 3.10-2 below.

Table 3.10-2: Definitions of selected kinematic test parameters used in thesis studies.

Terms	Units	Definitions
Blade forward reach (Reach water contact)	m	The horizontal distance from the front edge of a paddler’s seat to the water contact point of their paddle blade during the catch phase of the paddling stroke.
Blade displacement on water surface	m	The horizontal distance on the water surface between the water contact point and water exit point of the paddle blade for a paddling stroke.

Boat displacement per stroke	m	The horizontal distance moved by the boat during a paddling stroke.
Boat velocity average	m/s	The average speed of a boat during a paddling stroke.
Boat velocity during propulsion	m/s	The average speed of a boat during the time the paddle is in the water for a paddling stroke.
Paddle angle water contact	deg	The angle of the paddle relative to the vertical at the time of water contact.
Paddle angle maximum force	deg	The angle of the paddle relative to the vertical at the time of maximum paddle force in water.
Paddle angle zero force in water	deg	The angle of the paddle relative to the vertical at the time of zero paddle force in water.
Paddle angle water exit	deg	The angle of the paddle relative to the vertical at the instance of time when the paddle blade leaves the water.
Paddle angle zero force air	deg	The angle of the paddle relative to the vertical at the time of zero paddle force in air.
Paddle angular velocity in water	deg/s	The average rate of angular rotation of the paddle during the water phase of the paddling stroke.
Paddle stroke length	m	The length of the paddling stroke from the point of water contact to the point of water exit measured relative to the boat on a horizontal line parallel to the water surface.

The selected temporal test parameters and their definitions are shown in Table 3.10-3 below.

Table 3.10-3: Definitions of selected temporal test parameters used in thesis studies.

Terms	**Units**	**Definitions**
Stroke rate	spm	The term used by paddlers and coaches to describe the rate of paddling action. It is the reciprocal of the stroke time expressed in terms of strokes per minute.
Stroke time	s	The period of time between water contact of one paddling stroke to water contact of the subsequent paddling stroke. When only force data are available stroke time is the time between the occurrences of the initial zero force events in water subsequent to the maximum force event occurring in consecutive paddling strokes.
Stroke time catch propulsive (water component)	s	The time duration of the water component of the catch phase of the paddling stroke – • from water contact to full blade immersion when only kinematic data are available • estimated by 50 percent of the time from zero force in air to maximum force on the paddle in water when only kinetic data are available • from water contact to maximum force on the paddle in water when both kinetic and kinematic data are available
Stroke time drive	s	The time duration of the drive phase of the paddling stroke - • from maximum paddle force to zero paddle force

		in water when kinetic data are available • from full blade immersion to start of paddle exit when only kinematic data are available
Stroke time propulsive	s	The time duration of the propulsive water phase of the paddling stroke – • from water contact to start of paddle exit when only kinematic data is available • estimated by the time from zero force in air to zero force in water less 50 percent of the time from zero force in air to maximum paddle force when only kinetic data are available
Stroke time recovery	s	The duration of the recovery phase of the paddling stroke • from zero paddle force in water to zero paddle force in air when kinetic data are available • from the start of paddle exit to the time of paddle set-up position when only kinematic data are available
Stroke time propulsive ratio	ratio	The ratio of paddle propulsion time (stroke time propulsive) to the time duration of a paddling stroke

3.11 Data analysis

Upon analysis of the data it was discovered that four video clips from the first day of testing were not usable because only a partial recording of the paddling strokes were made. It was also discovered that force data in one case was not recorded by the system. During testing it was not possible to check the results and subsequently it was not possible to repeat the tests. Hence only the available usable data could be analysed. Thus for team 2, the less successful boat crew, a full set of kinetic and kinematic data was available for twelve paddlers (two more skilled male, five less skilled male and five less skilled female paddlers). On the second day of testing the force recording system malfunctioned and failed to record data for the last seven paddlers tested. Hence for team 1, the more successful boat crew, a full set of kinetic and kinematic data was available for ten paddlers (two more skilled male, four more skilled female, two less skilled male and two less skilled female paddlers).

Overall on a team basis ten results from the more successful boat crew (team 1) and twelve results from the less successful crew (team 1) were available for analysis. When paddlers were grouped on the basis of skill, data for eight skilled paddlers and fourteen less skilled paddlers were available. Both sets of results were considered to be acceptable for performance comparison and statistical analysis.

The video clips of the single paddling stroke for each paddler were analysed via Silicon Coach Pro 7 software (Silicon Coach, NZ) and the resultant kinematic data were processed in a custom made Excel spreadsheet. Kinetic data derived from the force measuring system were also processed in a similar manner. An Excel spreadsheet was developed to analyse the force data and combine the calculated kinetic and kinematic test parameters for the studies. All test parameters were checked for normality and bivariate outliers via scatter plots and their relationships were visually inspected. When an outlier was found it was removed from the data set and this action was noted and explained in the result section of the study.

3.12 Statistical evaluation

Statistical evaluation was performed via a custom made Excel spreadsheet. For all studies the average, standard deviation, statistical significance, 95 percent confidence limits of the sample (±1.96*standard error of the sample) and Cohen's effect size for each test parameter were calculated and reported. Unequal variance student t-tests were used for statistical evaluation. The standard significance level of $p<0.05$ was set to test the null hypothesis for each test parameter.

For all studies single-sided unequal variance student t-tests were used since expectations for the test parameter results were known. In study 1 on the operationalisation of a good dragon boat paddling stroke the results of more skilled paddlers were expected to be superior to the less skilled. For study 2 comparing a more successful dragon boat racing crew with a less successful one the racing performance record of each crews was already known. Hence the test parameter results of the more successful crew were expected to be superior to that of the less successful crew. For studies 3 and 4 comparing the kinetic and kinematic performance of more and less skilled dragon boat paddlers, expectation was known. The more skilled paddlers were expected to produce superior performance compared to the less skilled.

The number of test parameters in each study was as follows -

Study 1 – nine parameters:

Forward reach water contact, set up height, vertical paddle velocity in air, force rate increase, maximum paddle force, drive impulse, drive impulse rate, force rate reduction and recovery impulse.

Study 2 – thirteen kinetic, twelve kinematic and seven temporal parameters:

Kinetic: force average catch (propulsive), force average drive, force paddle water contact, force paddle maximum, force paddle vertical, force paddle minimum, force quality drive, force rate increase, force rate reduction, stroke impulse catch (propulsive), stroke impulse drive, stroke impulse drive rate and stroke impulse recovery.

Kinematic: paddle blade forward reach, blade displacement at the water surface, boat displacement per stroke, boat velocity average, boat velocity during propulsion, paddle angle at water contact, paddle angle at maximum force, paddle angle at zero force in water, paddle angle at water exit, paddle angle at zero force in air, paddle angular velocity in water and paddle stroke length.

Temporal: stroke rate, stroke time, stroke time catch propulsive (water component), stroke time drive, stroke time recovery, stroke time propulsive and stroke time propulsive ratio.

Study 3 – thirteen kinetic and seven temporal parameters as in study 2

Study 4 – twelve kinematic parameters as in study 2 and one temporal

As can be seen above each study uses multiple test parameters. In such situations the standard Bonferroni procedure or Holm's (1979) sequential Bonferroni method is often used to correct multiple significance testing (Nakagawa, 2004). These methods are designed to protect against the occurrence of type I error (rejecting the null hypothesis when in fact the null hypothesis is true). However in doing so the likelihood of making a type II error (accepting the null hypothesis when it is false) is increased and statistical power is reduced (Nakagawa, 2004). Perneger (1998) is of the view that Bonferroni adjustments of statistical significance for multiple tests create more problems than it solves. He states that the Bonferroni method addresses the problem of all the null hypotheses of the multiple tests being true simultaneously, a situation which is unlikely to occur in practice. Using such corrections force the interpretation of findings to depend on other significance tests, increasing the likelihood of type II errors and reducing statistical power (Perneger, 1998).

When large numbers of variables are involved Perneger (1998) recommends an explanation of what significance tests have been done and the reasons for them. Nakagawa (2004) recommends that effect size and confidence intervals be used in lieu of corrections for multiple significance testing. Ruxton & Beauchamp (2008) recommend that comparisons of variables be planned a priori. By comparing only variables of interest the risk of type I errors are reduced. Some influential texts consider that control for experimental type I error rate is not required if each comparison tests a different hypothesis (Kirk, 2013).

In view of the above recommendations the author decided to adopt the “no correction” approach for the following reasons. The studies of this thesis are exploratory; the test parameters measure different practical aspects of the action phases and key events of the paddling stroke. Only variables of interest to practitioners of the sport are compared and these variables are derived from the theoretical model of dragon boat paddling.

CHAPTER 4

Study 1 Operationalising the coaching model of a good dragon boat paddling stroke

4.0 Purpose of study

Paddling technique is of paramount importance in dragon boat racing. Success in racing requires an effective paddling technique that generates boat speed; successful paddlers need produce good paddling strokes consistently. What is a good dragon boat paddling stroke is a question that has occupied the minds of many coaches and paddlers. Over time through trial and error, a qualitative description of a good dragon boat paddling stroke has emerged. This coaching model can be stated as follows; a good dragon boat paddling stroke has *a high set-up, maximum reach, an aggressive catch, a powerful drive, a quick exit and a smooth recovery*. Coaches use this model to instruct paddlers on how to paddle and develop an effective paddling technique for dragon boat racing. However there is no biomechanical evidence to support this model of a good dragon boat paddling stroke. It needs to be tested and evaluated. Operationalisation is the process by which this task can be accomplished (Emmerich at al., 2016). The aims of this study are to operationalise (convert) the qualitative concepts of the coaching model of a good dragon boat paddling stroke into quantitative variables that can be observed, measured and tested so that its biomechanical support can be evaluated.

4.1 Introduction

Operationalisation is ‘the process of defining a fuzzy concept so as to make it clearly distinguishable, measurable, and understandable in terms of empirical observations’ (Wikipedia – accessed March 10, 2018). It was first proposed in physics by Campbell (1920) and popularised by Bridgman (1927). Later operationalism was applied to other fields of knowledge including psychology (Feest, 2005; Hardcastle, 1995; Stevens, 1935), economics (Samuelson, 1947; Wade-Hands, 2004), computer games Emmerich et al., (2016) and education (Lakshmi et al., 2017).

Before operationalising a good dragon boat paddling stroke a basic description of a dragon boat paddling stroke needs to be reviewed. Dragon boat paddling is a cycling process that consists of three phases of action - catch, drive and recovery interlinked by a smooth sequence of movements. The catch phase begins from the paddle set-up position in air (zero paddle force in air) and concludes with full blade immersion (maximum paddle force in water). It has an air component from paddle set-up to water contact and a water component from water contact to full blade immersion. The drive phase starts with full blade immersion and ends when the paddle force in water falls to zero (start of paddle exit from the water). It has a water only component, from full blade immersion to the moment of zero paddle force in water. The recovery phase begins with the start of paddle exit from the water and concludes with paddle set-up in air. It has paddle exit as the water component and movement to the set-up position as the air component. Together these five components of the three action phases blend together to form a sequence of movements that produce a paddling stroke.

The operationalisation of a good dragon boat paddling stroke needs to be understood in terms of the theoretical model of the dragon boat paddling stroke. Each kinetic test parameter assigned to the fuzzy concepts describing the action phases of the paddling stroke needs to be understood with respect to the force-time diagram, key events and action phases of the theoretical model shown in Figure 3.7-1 of Chapter 3 and reproduced herein.

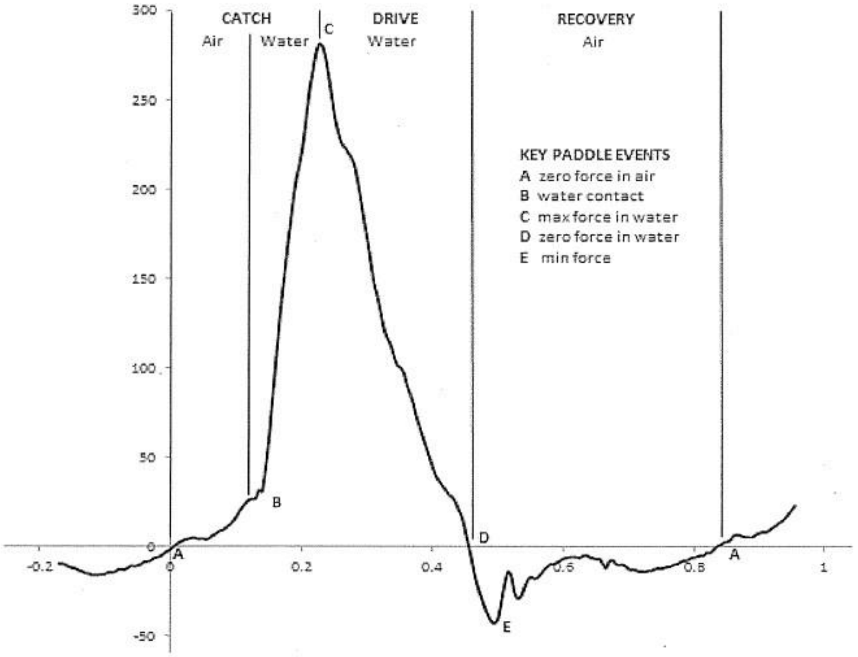

Figure 3.7-1: Key paddle events and phases of a racing paddling stroke.

The fuzzy qualitative concepts of the model for a good dragon boat paddling *a high set-up ,maximum reach , an aggressive catch, a powerful drive, a quick exit and a smooth recovery* is operationalised by assigning measurable test parameters to each of these concepts to enable the model to be tested and evaluated. A *high set-up* can be quantified by making hand height of the inboard hand relative to water the test parameter (quantitative variable) and measuring this height at the paddle set-up position when the force on the paddle in air during the recovery phase is zero. *Maximum reach* can be made concrete and measureable by assigning the horizontal distance between the paddle blade tip at water contact and the front edge of the paddler's seat the quantitative variable and test parameter.

For *high set-up* and *maximum reach* one variable is sufficient to define the concept. However *an aggressive catch*, a *powerful drive*, a *quick exit* and a *smooth recovery* are more complicated concepts and for a definition all but one of them requires more than one operational variable (test parameter). An *aggressive catch* implies speed and high forces. The catch phase of a paddling stroke has two components, an air component and a water component. Therefore it seems logical to quantify *an aggressive catch* by the average vertical velocity of the paddle in air and the rate of average force increase on the paddle as the blade enters the water and reaches full immersion. A *powerful drive* implies a high force sustained over time so maximum paddle force, drive impulse (force-time duration), and drive impulse rate (paddling effort) are suitable test parameters (quantitative variables) to measure this concept. *Quick exit* implies speed and therefore a rapid reduction of the paddle force as the paddle blade is extracted from the water. Hence the rate of force reduction just prior to paddle exit is an appropriate operational variable. *Smooth recovery* implies smooth movements of the paddler and the paddle during the air phase of the paddling stroke. This requires low acceleration and thus low forces on the paddle during the time of recovery. Thus recovery impulse (the area under the force-time curve between paddle exit and paddle set-up positions) is a suitable test parameter for the concept of *smooth recovery*.

In summary the quantitative test parameters are *set up height, reach water contact, vertical paddle velocity in air, force rate increase, maximum paddle force, drive impulse, drive impulse rate, force rate reduction and recovery impulse.* This study compares the results for the operationalised test parameters of more skilled paddlers with those less skilled via Student t-tests in order to evaluate the support for the model for a good dragon boat paddling stroke. More skilled paddlers are expected to have a superior paddling technique and be using good dragon boat paddling strokes. Their performance for the operationalised test parameters should be statistically significant with respect to the less skilled group of paddlers if the model is valid.

Table 4.1-1 describes the operationalisation process for the concepts of a good dragon boat paddling stroke; *maximum reach, a high set-up, an aggressive catch, a powerful drive, a quick exit and a smooth recovery* in terms of measurable test parameters.

Table 4.1-1: Operationalising the model of a good dragon boat paddling stroke.

Concept	**Test Parameter**	**Definition of measurable test parameter**
High set up	Set up height	The point at the end of the recovery phase of a paddling stroke from which the catch phase of the stroke begins. It is the point at which the paddle handle is at its maximum vertical position and where the paddle motion changes from forward and up to forward and down.
Maximum reach	Reach water contact	The horizontal distance from the front edge of a paddler's seat to the water contact point of the paddle blade tip at the start of the water component of the catch phase of a paddling stroke.
Aggressive catch	Vertical air velocity Force rate development	The average vertical velocity of the paddle from its set-up position to the time of water contact of the paddle blade measured via the paddle handle positions. The slope of the straight line on the force-time diagram from 20 percent of maximum force to 80 percent of maximum force during the water component of the catch phase of a paddling stroke.
Powerful drive	Max paddle force Drive impulse Drive impulse rate	The maximum force on the paddle in water at the end of the catch phase of a paddling stroke and the beginning of the drive phase. The area under the force-time curve for the drive phase of the paddling stroke from the time of maximum paddle force on water to the first time of occurrence of zero force on the paddle in water. The product of drive phase impulse (N.s) and stroke rate (spm) for a paddling stroke divided by 60 and expressed as Newton seconds per second. It is used to normalise the drive impulse to the unit of time and thereby enable performance comparisons to be made between paddlers for the drive phase of the stroke.
Quick exit	Force rate reduction	The slope on the force time diagram for the straight line at the end of the drive phase of the paddling stroke from 20 percent of maximum force on the paddle to the first time of occurrence of zero force on the paddle in water.
Smooth recovery	Recovery impulse	The area under the force-time curve of the paddle from the first time occurrence of zero force on the paddle in water to the time of zero force on the paddle in air for a paddling stroke. It is used to measure the smoothness of the recovery phase of the paddling stroke. The magnitude of both positive and negative areas are added together to obtain this parameter.

4.2 Methods

Full details of the research strategy and selection of test subjects, test equipment, calibration and synchronisation, test procedures, description of the theoretical model of a dragon boat paddling stroke used to develop the definition of terms, selection of test parameters, data analysis and statistical evaluation, are described in Chapter 3 – Methods. A summary of the methods and specific details of the data analysis and evaluation process applicable to this study are covered in the current chapter.

Volunteer paddlers from three Melbourne dragon boat clubs participated in this study. Informed consent from all participants was obtained prior to testing and the test procedures had prior ethics committee approval. Each participant carried out a 30 s maximum effort paddling test within a boat crew setting at racing pace. A minimum of two minutes rest between each test run was allowed for recovery. Kinetic data were collected from each test participant at 200 Hz via a custom built strain-gauged paddle that was passed to a new participant at the end of each test. Kinematic data were recorded for one paddling stroke for each participant via a stationary video camera (Sony HDR-HC7) operating at 200 Hz.

For data analysis the participants of this study were grouped on the basis of skill. Paddlers who had represented their state at the Australian championship or had represented Australia at an international regatta were classified as being more skilled paddlers. All other paddlers were classified as being less skilled. Data from eight more skilled (four male and four female) and fourteen less skilled (seven male and seven female) paddlers was collected for evaluation. There was no significant difference between the more skilled and less skilled group of paddlers with respect to age (53.3 ± 8.7 versus 44.5 ± 15.7 years, $p = 0.054$, $d = 0.67$) and body mass (70.4 ± 10.5 versus 75.3 ± 14.6 Kg, $p = 0.19$, $d = 0.39$).

Statistical analysis of the results was carried out via an Excel spreadsheet. A one-tailed unequal variance student t-test at $p<0.05$ was used for significance testing as expectation was known; more skilled paddlers were expected to perform better than the less skilled group of paddlers with respect to the operationalised test parameters defining a good dragon boat paddling stroke. Cohen's effect size and 95 % confidence intervals of the sample along with standard deviations were calculated and reported for each test parameter.

The qualitative coaching model of a good dragon boat paddling stroke was operationalised by assigning measurable test parameters to each of its qualitative concepts. Support for the model was assessed by comparing the performance of more skilled paddlers against the less skilled group via Student t-tests. For the model to be supported the performance of the more skilled paddlers needed to be significant and superior to that of the less skilled group.

4.3 Results

The forward reach of the paddle at water contact was significant and greater for the more skilled group of paddlers than for the less skilled (1.34 versus 1.26 m, $p = 0.044$, $d = 0.75$). However there was no significant difference between the groups for paddle set-up height and vertical paddle velocity in air. The force rate development during water entry (2540 versus 1337 N/s, $p = 0.005$, $d = 1.63$) and the force rate reduction leading to paddle exit (-575 versus -260 N/s, $p = 0.014$, $d = 1.30$) were significant and higher in magnitude for the more skilled paddlers. For the drive phase of the paddling stroke, maximum paddle force (276 versus 191 N, $p = 0.009$, $d = 1.24$), drive impulse (43 versus 22 N.s, $p = 0.006$, $d = 1.56$), and drive impulse rate (49 versus 25 N.s/s, $p = 0.003$, $d = 1.65$), were all significant and higher for the more skilled group of paddlers than for the less skilled. However the impulse recovery (4.3 versus 5.8 N.s/s, $p = 0.028$, $d = -0.84$) whilst significant was less for the more skilled group than for the less skilled paddlers. Thus seven of the nine operationalised test parameters for the model of a good dragon boat paddling stroke were statistically significant and gave strong support to the model (Table 4.3-1).

T**able 4.3-1: Results for the operationalised test parameters of the model for a good dragon boat paddling stroke for more skilled versus less skilled paddlers during 30 s maximum effort paddling tests simulating a dragon boat race.**

Paddling Skills Group Statistics			More skilled N=8			Less skilled N=14			One tail	Effect size
Model concepts	**Test parameters**	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
High set-up	Set-up height	m	1.18	0.06	0.09	1.19	0.09	0.17	0.389	0.11
Maximum reach	Reach water contact	m	**1.34**	0.05	0.08	**1.26**	0.07	0.13	**0.044**	0.75
Aggressive catch	Vertical air velocity	m/s	0.46	0.26	0.37	0.69	0.27	0.52	0.120	0.52
	Force rate develop't	N/s	**2540**	685	989	**1337**	327	635	**0.005**	**1.63**
Powerful drive	Max paddle force	N	**276**	50	72	**191**	37	71	**0.009**	**1.24**
	Drive impulse	N.s	**43**	12	18	**22**	6	12	**0.006**	**1.56**
	Drive impulse rate	N.s/s	**49**	12	18	**25**	7	14	**0.003**	**1.65**
Quick exit	Force rate reduction	N/s	**-575**	215	311	**-260**	113	216	**0.014**	**1.30**
Smooth recovery	Recovery impulse	N.s	**4.3**	1.0	1.4	**5.8**	1.1	2.1	**0.028**	**0.84**

Note: Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

In summary all operationalised test parameters for the qualitative concepts of *maximum reach*, *powerful drive*, *quick exit* and *smooth recovery* were statistically significant with large effect sizes. One of the operationalised test parameters for the concept of *aggressive catch*, the rate of force increase was statistically significant with a large effect size whilst the other test parameter, average paddle velocity in air, was not significantly different. The set-up height test parameter for the concept of *high set-up* was also not significant. Overall these results indicate a strong support for seven of the operationalised parameters of the model for a good dragon boat paddling stroke and suggest that two non-significant operationalised parameter should be removed from the model.

The coefficient of determination for test parameters of the model for a good dragon boat paddling stroke are shown in Table 4.3-2 with the parameters for model concepts having more than one test parameter shown boxed and test parameters having a coefficient of determination $R^2 > 0.3$ ($r > 0.54$) shown bold. The three test parameters for the concept of a *powerful drive* are highly correlated with each and thus have large coefficients of determination, indicating that they are an integral part of the *powerful drive* concept. However the two parameters for the concept of *aggressive catch* have a very low coefficient of determination between them and thus the non-significant test parameter, average vertical velocity of the paddle in air, is not an integral part of the *aggressive catch* concept.

Table 4.3-2: Coefficient of determination for each operationalised test parameters of the model for a good dragon paddling stroke relative to all operationalised test parameters.

Coefficient of Determination R^2	***Reach water contact***	***Set-up height***	***Vertical air velocity***	***Force rate incr***	***Max paddle force***	***Drive impulse***	***Drive impulse rate***	***Force rate reduct***	***Recovery impulse***
Reach water contact	1								
Set-up height	0.06	1							
Vertical air velocity	0.07	**0.66**	**1**						
Force rate developm't	0.09	0.004	**0.008**	**1**					
Max paddle force	0.16	0.06	0.06	**0.62**	**1**				
Drive impulse	0.17	0.12	0.11	0.28	**0.62**	**1**			
Drive impulse rate	0.19	0.10	0.09	**0.37**	**0.71**	**0.98**	**1**		
Force rate reduction	0.12	0.02	0.04	0.27	**0.36**	0.29	***0.37***	1	
Recovery impulse	0.12	0.02	0.0003	0.18	0.13	0.29	***0.31***	0.24	1

Note: Parameters with $R^2 > 0.3$ are shown bold and R^2 values for the concepts of *aggressive catch* and *powerful drive* are boxed.

High coefficient of determination values exist between the test parameter pairs of set-up height and vertical paddle velocity in air (0.66) and paddle force rate increase and maximum paddle force (0.62). These results are due to the high correlation and close relationship between the test parameter pairs and thus are in line with expectation. Moderate values exist between force rate increase and drive impulse rate (0.37), maximum paddle force and force rate reduction (0.36), drive impulse rate and force rate reduction (0.37), and drive impulse rate and recovery impulse (0.31). The correlation between these parameter pairs are all > 0.54 indicating a moderate relationship between them.

4.4 Discussion

Operationalisation is a well-known and used process in social sciences. However to the author's knowledge it has not been used in the biomechanics literature. Regardless of this fact it is a valid and reliable approach. Perhaps other researchers in biomechanics may use it in the future.

The fact that the results for seven out of the nine operationalised test parameters that express the coaching model for a good dragon boat paddling were significantly superior for the more skilled group of paddlers indicates a high level of support for the coaching model. Four of the six concepts for the coaching model (*maximum reach, a powerful drive, a quick exit and a smooth recovery*) were fully supported with all their operationalised test parameters being significantly superior for the more skilled paddlers. One concept of the coaching model (*an aggressive catch*) had partial support with one of its operationalised test parameter (force rate development on the paddle) being statistically significant whilst its other operationalised test parameter (vertical paddle velocity in air) was not significant. The result for the operationalised test parameter (set-up height) for the concept of *a high set-up* was not significant and thus gave no support for the concept of *a high set-up*.

Based on the outcome of this study the model for a good dragon boat paddling stroke requires revision. The concept of *a high set-up* needs to be removed from the coaching model and the operationalised test parameter, vertical paddle velocity in air, needs to be removed from the concept of *an aggressive catch.* Thus the model for a good dragon boat paddling stroke now becomes the following; a good dragon boat paddling stroke has *maximum reach, an aggressive catch, a powerful drive, a quick exit and a smooth recovery*. The operationalised test parameters remain the same for all concepts except for *an aggressive catch* which now is reduced to one, the rate of force increase on the paddle during water entry. The revised coaching model for a good dragon boat paddling stroke needs to be tested and replicated by other researchers for it to be considered accurate and fully validated. However the support given to the model by this study is sufficient for it to be continued to be used to teach dragon boat paddlers good paddling technique and paddling skill with a good degree of confidence.

4.5 Conclusion

In this study the qualitative coaching model of a good dragon boat paddling stroke was operationalised by assigning measurable test parameters to its descriptive concepts. More skilled paddlers were tested against less skilled paddlers using biomechanical variables (measurable test parameters). All but two results were statistically superior for the more skilled group of paddlers giving good support for the coaching model. The model was revised to reflect the findings of this study and restated as follows: a good dragon boat paddling stroke has *maximum reach, an aggressive catch, a powerful drive, a quick exit and a smooth recovery*. This revised coaching model is most reflective of the skill-differences between paddlers and can be considered to be accurate and valid. Together these expressions form a coaching model for a good dragon boat paddling stroke that coaches can use to teach dragon boat paddlers good paddling technique and paddling skill.

CHAPTER 5

Study 2 Comparison of a more and a less successful dragon boat racing crew: kinetic, kinematic and temporal analysis of the paddling stroke

5.0 Purpose of study

Performance in dragon boat racing is measured via race times. Success depends on the average boat speed a crew can generate via paddle propulsion. How the paddle moves in water and the forces it generates determine the propulsive forces that create boat speed. The aim of this study is to establish the temporal, kinetic and kinematic parameters of the paddling stroke that differentiate a more successful dragon boat racing crew from a less successful crew.

5.1 Introduction

In dragon boat racing performance is measured via race times at the crew level. The crew that finishes first has the fastest time and the highest average boat speed. Winning crews are considered to have superior skill and fitness compared to less successful racing crews. When tested members of a winning crew are expected to perform at a higher level than members of less successful crews. However the kinetic and kinematic parameters of skill and fitness in dragon boat racing that separate paddlers of winning crews from less successful crews are not known. There have been no quantitative crew level studies published on the biomechanics of dragon boat racing. The only available information on performance at the crew level is a qualitative abstract by Pease (1997) whose main findings (see Chapter 2) were that boat crews with small framed paddlers tended to have higher stroke rates, shorter stroke lengths and shorter boat travel per stroke, with a larger angle of paddle entry than crews with large framed paddlers.

High performance in dragon boat racing is achieved by high boat speeds. Boat speed is generated by the paddling process of the crew. Body movements of paddlers move the paddle, but at the fundamental level it is the movement of the paddle in water that produces boat propulsion. The kinetics and kinematics of paddle propulsion need to be understood before human movement in paddling can be productively studied. Human motion depends on anthropometry. The paddle movement needed for effective propulsion may be produced by differing body motions of paddlers. Hence this study is focused on the kinetic, kinematic and temporal characteristics of the paddle to establish the propulsive parameters that differentiate a more successful dragon boat racing crew from a less successful crew.

5.2 Methods

Full details of the research strategy and selection of test subjects, test equipment, calibration and synchronisation, test procedures, description of the theoretical model of a dragon boat paddling stroke used to develop the definition of terms, selection of test parameters, data analysis and statistical evaluation, are described in Chapter 3 – Methods. A summary of the methods and specific details of the data analysis and evaluation process applicable to this study are covered in the current chapter.

Volunteer paddlers from three Melbourne dragon boat clubs participated in this study in a crew setting over two days on a weekend one month prior to the commencement of the racing season. On the first day a combined crew consisting of the two less successful clubs was tested. The more successful crew from a single club was tested on the following day. Informed consent from all participants was obtained prior to testing and the test procedures had prior ethics committee approval. Each participant carried out a 30s maximum effort paddling test within a boat crew setting at racing pace. A minimum of two minutes rest between each test run was allowed for recovery. Kinetic data were collected sequentially from each test participant at 200 Hz via a custom built strain-gauged paddle that was passed to a new participant on each test run. Kinematic data were recorded for a paddling stroke for each participant via a stationary video camera (Sony HDR-HC7) operating at 200 Hz.

For data analysis the participants of this study were grouped on the basis of crew membership with the skill level of each crew member noted and recorded. Paddlers who had represented their state at the Australian championship or had represented Australia at an international regatta were classified as being more skilled paddlers. All other paddlers were classified as being less skilled. Data from ten less skilled (five male and five female) and two more skilled (male) paddlers was collected from the less successful dragon boat crew for evaluation. For the more successful boat crew data from six more skilled (two male and four female) and four less skilled (two male and two female) was collected.

The average age and body mass of the more successful boat crew was 44.6 ± 9.9 years and 73.5 ± 9.2 Kg whereas for the less successful crew it was 54.1 ± 13.9 years and 73.1 ± 13.5 Kg. Two-sided Student t-test indicated a significant difference between the crews with respect to age ($p=0.026$) but not body mass ($p=0.92$). It is known that maximal oxygen consumption declines (Hawkins & Wiswell, 2003) and that the force–velocity relationship deteriorates (Raj, Bird & Shield, 2010) with age. The decrease in performance from the mid 30's is curvilinear until the mid 60's when it becomes exponential (Reaburn & Dascombe, 2008). This decrease in performance applies to all sports but rowing shows the least deterioration (Baker & Tang, 2010).

Rowing Australia Masters Commission Handicap Sub-Committee_analysed data from FISA Masters regattas and derived a relationship for the decline in boat speed as a function of age. Their report recommended a revision to the masters' handicap tables to reflect current performance of middle age grade rowers. Table 5.2-1 was constructed from the handicap sub-committee data and shows the percentage decline in rowing performance as a function of age.

Table 5.2-1: Decline in rowing performance as a function of age based on Rowing Australia Handicap Sub-Committee Report and Recommendation (2013).

Age of rowing athlete	31	39	46.5	52	57	62	67	72	77	82	87
Performance decline %	0	0.45	2.1	4.1	6.3	8.9	11.8	15.3	20.1	27.1	35.7

The data contained in Table 5.2-1 is shown in chart form in Figure 5.2-1. It is evident that the decline is non-linear as a function of age and increases rapidly once the age of 70 is reached.

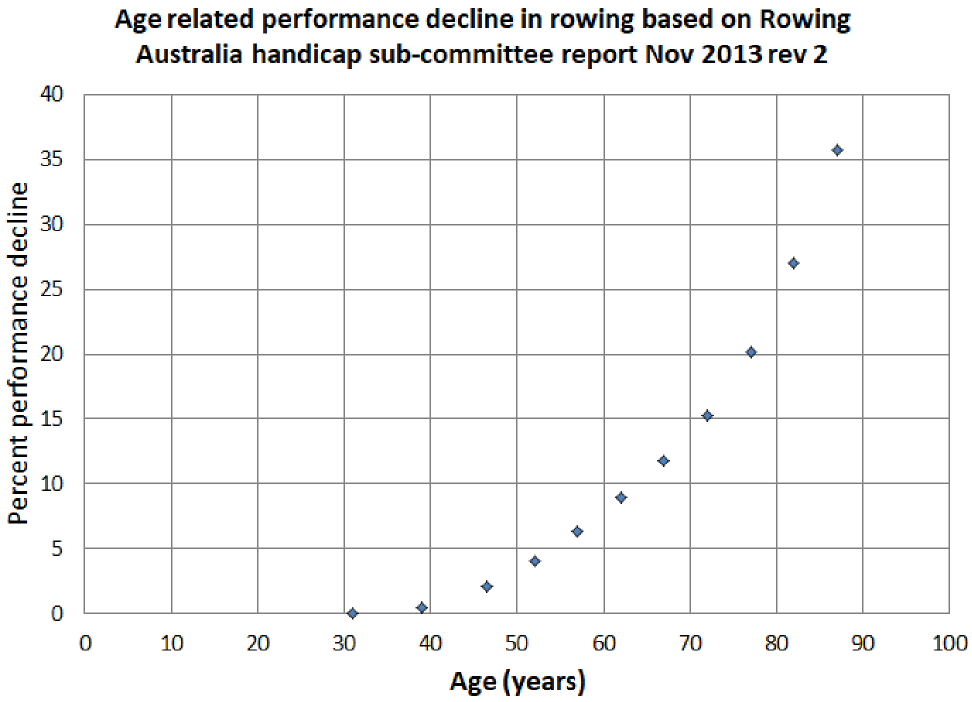

Figure 5.2-1: Chart for age related performance decline derived from Rowing Australia Masters Commission Handicap Sub-Committee Report and Recommendation data.

The Rowing Australia data in effect provides a measure of the decline in power output of rowers as a function of age. As such the data should be applicable to dragon paddling. For the average age difference of this study (44.6 v 54.1 years, p = 0.026) rowing crews would expect to experience a 3.8 percent decrement in performance. Kinematic parameters of the study that require generation of power (boat velocity average, boat velocity propulsion and paddle angular velocity in water) were evaluated for age adjustment. However the significance of the results (Table 5.3-2) was not altered by age adjustment. Therefore age adjustment of performance was deemed not to be necessary for this study.

Statistical analysis of the results was carried out via Excel spreadsheets. A single sided unequal variance student t-test at $p<0.05$ was used for significance testing since it was known which crew had the superior racing record and it was expected that the test results for that crew would be superior. Cohen's effect size and 95 % confidence intervals along with standard deviations were calculated and reported for each test parameter. Scatter plots for each test parameter were used to check the data for bivariate outliers and to visually inspect each relationship. When found, outliers were removed from the data set and the details reported in the results section of the study.

5.3 Results

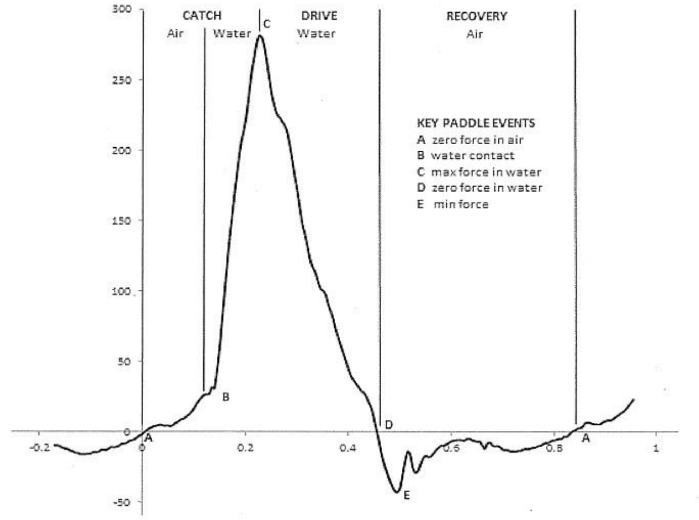

Figure 3.7-1: Key paddle events and phases of a racing paddling stroke.

Figure 3.7-1 is reproduced herein to assist the understanding of the results with respect to the theoretical model of the dragon boat paddling stroke. The kinetic, kinematic and temporal results for the test parameters of key paddle events and phases of the paddling stroke need to be viewed in context with respect to this model.

Overall four of the thirteen kinetic, seven of the twelve kinematic and three of the seven temporal paddle test parameters were significant and produced superior performance for the more successful dragon boat crew. The four significant kinetic paddle parameters were the rate of force development (gradient of the paddle force) during water entry (2244 v. 1383 N/s, $p = 0.021$, $d = 1.04$), the average force during the drive phase of the paddling stroke (92 v. 47 N, $p = 0.019$, $d = 1.06$), force quality (ratio of average drive force to the maximum paddle force) for the drive phase (0.35 v. 0.21, $p = 0.023$, $d = 1.17$), and the rate of force reduction just prior to paddle exit (-561 v. -220 N/s, $p = 0.011$, $d = 1.49$). Each kinetic paddle parameter that was significant had a large effect size.

The nine non-significant kinetic paddle test parameters were the average force during the catch phase of the paddling stroke, the key paddle event forces (water contact, maximum force, vertical position and minimum force) and the impulse parameters (catch, drive, drive-rate and recovery). Of these non-significant results all five force parameters along with two impulse parameters were higher for the more successful boat crew with the average catch, maximum and vertical paddle forces and the recovery impulse all having moderate effect sizes.

Four kinetic parameters that did not reach significance had low p values (0.073 to 0.097) and moderate effect sizes (0.59 to 0.70) indicating that with crews of different ability or larger sample size (full crew of 20 paddlers) these parameters could also become significant. These four parameters were force average catch, force average maximum, force average vertical paddle position and stroke impulse during recovery.

The results for all thirteen kinetic and seven temporal paddle test parameters are shown in Table 5.3-1 below.

Table 5.3-1: Crew level kinetic and temporal performance: a more successful boat crew versus a less successful boat crew during 30 s maximum effort paddling tests simulating a dragon boat race.

GROUP STATISTICS		More successful N=10			Less successful N=12			One tail	Effect Size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Force average catch	N	149	33	54	121	24	43	0.097	0.62
Force average drive	N	**92**	34	54	**47**	20	35	**0.019**	**1.06**
Force paddle water contact	N	37	12	19	30	10	18	0.185	0.42
Force paddle maximum	N	251	54	88	198	40	70	0.073	0.70
Force paddle vertical	N	231	55	88	185	39	68	0.096	0.62
Force paddle minimum	N	-38	11	17	-36	7	12	0.388	0.13
Force quality drive	ratio	**0.35**	0.09	0.14	**0.21**	0.06	0.10	**0.012**	**1.17**
Force rate development	N/s	**2244**	658	1061	**1383**	385	681	**0.021**	**1.04**
Force rate reduction	N/s	**-561**	210	338	**-220**	60	105	**0.006**	**1.49**
Stroke impulse catch	N.s	19	5	8	19	5	9	0.438	0.07
Stroke impulse drive	N.s	31	8	12	28	12	21	0.348	0.17
Stroke impulse drive-rate	N.s/s	37	10	15	31	12	22	0.216	0.35
Stroke impulse recovery	N.s	4.7	0.8	1.3	5.8	1.3	2.4	0.092	0.59
Stroke rate (reference)	spm	**71**	1.5	2.1	**67**	2.1	3.4	**0.005**	**1.23**
Stroke time	s	**0.843**	0.021	0.029	**0.893**	0.032	0.051	**0.005**	**1.23**
Stroke time catch	s	**0.123**	0.025	0.035	**0.155**	0.014	0.021	**0.013**	**1.16**
Stroke time drive	s	0.291	0.032	0.045	0.305	0.039	0.061	0.265	0.28
stroke time recovery	s	0.430	0.026	0.037	0.433	0.029	0.043	0.415	0.05
Stroke time propulsive	s	0.414	0.030	0.041	0.460	0.043	0.067	**0.032**	**0.85**
Stroke time propulsive	ratio	0.490	0.031	0.043	0.513	0.035	0.055	0.143	0.48

Note: Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

Time analysis revealed three significant test parameters for the more successful boat crew; stroke time (0.843 v 0.893 s, p = 0.005, d = 1.23), catch duration (0.123 v 0.155 s, p = 0.013, d = 1.16) and propulsive time (0.414 v 0.460 s, p = 0.032, d = 0.85). The temporal parameters of the drive and recovery phase of the paddling stroke were not significant; each had high p values and a small effect size. The ratio of propulsion to stroke time was also not significant but its p value was lower and its effect size was higher than that of the drive and recovery phases of the paddling stroke.

The difference in time between the average times of the two crews for the catch, drive and recovery phases of the paddling stroke were 0.032, 0.014 and 0.003 s respectively. These parameters sum to 0.049 s which is within the measurement tolerance of the direct difference of 0.050 s between the two crews calculated from the average stroke times. The main difference between the crews is the significantly lower catch time for the more successful boat crew. This difference in catch time is the cause of the significantly higher stroke rate of the more successful dragon boat crew.

The seven kinematic parameters of significance that produced better results for the more successful boat crew were the average boat velocity (3.84 v. 3.47 m/s, p = 1.1E-04, d = 1.99, {age adjusted 3.71 v. 3.47 m/s, p = 0.003, d = 1.30}), boat velocity during propulsion (4.11 v. 3.59 m/s, p = 4.2E-06, d = 2.63, {age adjusted 3.97 v. 3.59 m/s, p = 1.1E-04, d = 1.98}), forward reach of the paddle (1.35 v. 1.25 m, p = 0.013, d = 1.06), paddle angle at maximum force (5.0 v. 9.1 deg, p = 0.028, d = 1.15), paddle angular velocity in water (49.0 v. 43 deg/s, p = 5.2E-05, d = 2.35, {age adjusted 47.4 v. 43 deg/s, p = 7.5E-04, d = 1.74}), paddle blade displacement relative to the water surface (0.16 v. 0.29 m, p = 0.040, d = 0.81) and stroke length (1.6 v. 1.4 m, p = 0.028, d = 0.88).

Kinematic results for crew performance with respect to the paddle and boat test parameters are shown in Table 5.3-2 with the parameter of stroke rate added as a temporal reference.

Table 5.3-2: Crew level kinematic performance: a more successful boat crew versus a less successful boat crew during 30 s maximum effort paddling tests simulating a dragon boat race.

GROUP STATISTICS		More successful N=10			Less successful N=12			One tail	Effect size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Blade forward reach	m	**1.35**	0.06	0.09	**1.25**	0.06	0.11	**0.013**	**1.06**
Blade displacement surface	m	**0.16**	0.09	0.15	**0.29**	0.10	0.18	**0.040**	**0.81**
Boat displacement per stroke	m	3.23	0.08	0.12	3.10	0.18	0.32	0.115	0.52
Boat velocity average	m/s	**3.84**	0.07	0.11	**3.47**	0.14	0.24	**1.1E-04**	**1.99**
- adjusted for age	m/s	**3.71**	0.07	0.11	**3.47**	0.14	0.24	**0.003**	**1.30**
Boat velocity propulsion	m/s	**4.11**	0.09	0.14	**3.59**	0.14	0.25	**4.2E-06**	**2.63**
- adjusted for age	m/s	**3.97**	0.08	0.13	**3.59**	0.14	0.25	**1.1E-04**	**1.98**
Paddle angle water contact	deg	33	2.8	4.5	34	2.7	4.8	0.322	0.21
Paddle angle max force	deg	**5.0**	1.7	2.6	**9.1**	3.4	4.9	**0.028**	**1.15**
Paddle angle zero force	deg	-52	4.6	7.1	-49	5.7	10	0.208	0.37
Paddle angle water exit	deg	-56	4.0	6.4	-54	4.4	7.8	0.218	0.35
Paddle angle zero force air	deg	26	5.2	8.4	23	6.4	11	0.266	0.29
Paddle angular velocity water	deg/s	**49**	1.9	3.1	**43**	1.3	2.3	**5.2E-05**	**2.35**
- adjusted for age	deg/s	**47.4**	1.9	3.0	**43**	1.3	2.3	**7.5E-04**	**1.74**
Paddle stroke length	m	**1.60**	0.11	0.16	**1.40**	0.16	0.28	**0.028**	**0.88**
Stroke rate (reference)	spm	**71**	1.5	2.1	**67**	2.1	3.4	**0.005**	**1.23**

Note: Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

Five of the seven kinematic parameters of significance were with respect to the paddle and two were concerned with boat speed. The paddle related kinematic significant parameters were forward reach of the paddle at water entry, stroke length, and paddle angle at maximum force, paddle angular velocity in water and paddle blade displacement relative to the water surface. All were significant with large effect sizes. The boat related velocity parameters were highly significant and substantially higher for the more successful crew even after allowing for age adjustment in performance.

Five kinematic paddle parameters were found to be not significant: average boat displacement per paddling stroke, and the paddle angles at water contact, zero force in water, paddle exit and zero force in air. The results were very similar for both crews. The effect size ranged from small (0.21) to moderate (0.52) values.

Although the average boat displacement per paddling stroke parameter did not reach significance it had a low p value (0.115) and a moderate d value (0.52) indicating that with crews of different ability or larger sample size (full crew of 20 paddlers) this parameter may become significant. It needs to be noted that at the 1997 Hong Kong World Cup Pease (1997) observed that small framed paddlers tended to have higher stroke rates, shorter stroke lengths and shorter boat travel per stroke whilst large framed paddlers tended to have lower stroke rates, greater stroke lengths and greater boat travel per stroke.

5.4 Discussion

The average stroke, catch and propulsive time (combined catch and drive time) for the more successful crew were significantly less than that of the less successful crew. These results are all due to the catch phase of the paddling stroke. The more successful crew had a more aggressive catch arising from the higher rate of force development on water entry. The average drive time was less but not significantly so for the more successful crew. Overall the more successful crew spent less time in the water per stroke than the less successful crew. Recovery time per stroke was almost identical for both crews. Thus the more successful crew was more efficient in their paddling technique than the less successful crew.

The significant kinetic paddle parameters were the average rate of force development during water entry, the drive force, the drive force quality (ratio of the average drive force to maximum paddle force), and the rate of force reduction prior to water exit. Paddlers in the more successful boat crew developed a more rapid rate of force development on water entry, reached a higher average drive force, maintained the higher drive force better during the drive phase of the paddling stroke and reduced the paddle force more quickly on paddle exit from the water.

The fact that only four of the thirteen kinetic paddle parameters were of significance and that three of the four were part of the drive phase of the paddling stroke, clearly shows the importance of the drive phase with respect to boat performance, paddling technique and skill. The drive phase of the paddling stroke is the key kinetic generator of average boat speed.

None of the other force parameters (catch, water contact, maximum, vertical and minimum forces) were of statistical significance due to the large standard deviations and confidence intervals of the results. This is likely to be due to the confounding effect of not having homogenous crews. Four out of the ten paddlers of the more successful boat crew were classified as being less skilled and it is likely that the overall results of the crew were diluted to such an extent that the differences between the more successful and the less successful boat crew became non-significant for these parameters. The results for the more successful boat crew came from six more skilled and four less skilled paddlers giving the crew a substantial degree of non-homogeneity whereas for the less successful boat crew the data came from ten less skilled and two more skilled paddlers which on the surface appears to make that crew more homogenous.

For the average catch, maximum and vertical paddle forces in this study the p values were low and the effect sizes were moderate, indicating that with different crews these parameters could become significant. In Chapter 6 kinetic parameters were compared on the basis of skill and hence the subject groups were more homogenous. On the basis of skill the difference between more and less skilled paddlers for the average catch, maximum and vertical paddle force parameters were all found to be significant. These results provide support for the non-homogenous crew explanation for the non-significant force results of this study.

The impulse parameter results in this study (catch, drive, drive-rate and recovery) were all non- significant. But in Chapter 6 with more homogenous groups the impulse parameters evaluated on the basis of skill were all significant, except for the catch impulse. Thus the skills based results provide further support for the non- homogenous crew explanation for the non-significant kinetic results.

Impulse parameters were found to be important and significant in canoeing (Sperlich & Baker, 2002) and kayaking (Wainwright et al., 2015) but not in dragon boating at the crew level in this study. Canoeing and kayaking are predominantly a sport for individuals whereas dragon boat racing is a team sport. Group composition affects statistical analyses and the confounding effects of a non-homogenous boat crew may produce non-significant statistical results.

Stroke impulse is the area under a force-time curve. It is a product of force and time. An impulse value may be produced by a range of force and time variables. Paddling technique determines the duration of the catch, drive and recovery phases of a paddling stroke. For an individual paddler the duration of the catch and drive phases directly affects the catch and drive impulse. In turn these time parameters affect the stroke rate. Since the force parameters were all higher for the more successful crew whilst the impulse parameters were almost identical for both crews the expectation is that the cause of the non-significant results are time related.

For an individual paddler the impulse value is calculated from their force-time data. However for a group the average impulse cannot be calculated from the average force-time data of the group; it can only be estimated since individual members of the group differ in performance. Using the reported average force and time data of the catch for each crew the estimated average catch impulse was calculated as 18.8 and 18.3 N.s for the more and less successful crew respectively. These values are very close to the 19 N.s results recorded for both crews. This estimate is accurate because due to the high rate of force development the shape of the force-time curve for the catch phase of a paddling stroke for each paddler closely approximates a right angled triangle for which the area is half the product of its base and height. The base of the triangle is the catch time and its height is the maximum force. Half of the maximum force is equal to the average force. Thus the area of the average triangle closely estimates the average impulse for each crew.

For the drive phase of the paddling stroke using the same procedure produced an estimate of 26.8 and 14.3 N.s for the average drive impulse for the more and less successful crews whereas the actual result was 31 and 28 N.s respectively. The estimate for the more successful crew loosely approximates the observed value but the estimate for the less successful crew is only half of the actual result. This is due to the shape of the drive force-time curve being irregular and the results for the drive impulse along with the average force being widely dispersed. In other words due to the non-homogenous nature of the two crews.

For members of the more successful crew consisting of six more skilled and four less skilled paddlers the drive impulse and drive force ranged from 13 to 59 N.s and 25 to 175 N with a group average of 31 N.s and 92 N. Similar analysis for members of the less successful crew consisting of two more skilled and ten less skilled paddlers produced a range from 6 to 75 N.s and 10 to 127 N for the drive impulse and drive force of the crew with a group average of 28

N.s and 47 N. These results indicate that both crews were non-homogenous and this fact alone explains the kinetic results for the drive phase of the paddling stroke.

With respect to the kinematic results two of the seven significant outcomes were boat related, average boat velocity and average boat velocity during propulsion. The more successful boat crew was significantly and substantially faster even after allowing for age adjustment (7 to 10 percent) than the less successful crew. The more successful crew paddled more effectively, was stronger and fitter than the less successful crew.

Five of the seven significant parameters were paddle related; paddle forward reach at water entry, paddle angle at maximum force, paddle angular velocity in water, paddle blade displacement relative to the water surface and stroke length. Paddlers from the more successful boat crew reached further forward at paddle entry, produced the maximum paddle force closer to the vertical paddle position, had a higher speed of paddle rotation in water, paddled at a higher stroke rate, had a longer stroke length and produced smaller horizontal blade displacement on the water surface.

All the significant kinematic paddle parameters had a large effect sizes especially the paddle angular velocity in water (49 v. 43 deg/s, p = 7.5E-04, d = 1.74) and the horizontal paddle blade displacement on the water surface (0.16 v. 0.29 m, p = 0.040, d = 0.81). These two results provide important objective measures of paddling performance, technique and skill. The paddle angular velocity gives an indication of a paddler’s strength and fitness and the horizontal blade displacement provides a measure of a paddler’s skill.

Paddle angular velocity is the average rate of angular rotation of the paddle during the water phase of the paddling stroke. The higher the angular velocity of a paddling stroke the greater is the power being generated by a paddler. The amount of power that a paddler can produce depends on the strength and fitness of the paddler. Stroke rate is controlled by the lead paddlers. For a given stroke rate a paddler can produce different levels of power by controlling the paddle angular velocity. Thus at maximum effort (as per test condition) paddle angular velocity provides a measure of the strength and fitness of a paddler.

The horizontal paddle blade displacement, that is the distance from water contact point of paddle blade on entry to the paddle blade water exit point, was in the direction of boat movement indicating paddle drag. The results indicate that whilst the paddle blade in water was being rotated, it was also being dragged along by the boat. An additional drag force was being imposed on the boat due to the paddling actions of the paddler. This retardation was due to the slow entry and exit of the paddle. If the paddle entry and exit speeds are matched to the boat speed then the paddle will enter and leave the water at the same point on the water surface so that the horizontal blade displacement becomes zero. The paddling stroke efficiency will be maximised as there will be no horizontal drag and the total surface area of the paddle blade will be fully utilised to produce boat propulsion via rotational slip. Thus horizontal paddle blade displacement can be used to provide an objective measure of paddling skill and efficiency.

None of the kinematic paddle angle key events apart from the paddle angle at maximum force were of statistical significance. Thus the angles of paddle entry and paddle exit appear not to be important with respect to performance, paddling technique or skill. Ho et al., (2009) also found the paddle angles at entry and exit to be non-significant. The fact that the paddle angle at maximum was significant and that this angle was close to but not at vertical paddle position is important as this finding contradicts the literature; Ho et al., (2009) stated that the maximum force on the paddle occurs at the vertical position. However their statement was an assumption and not an observed measured fact.

5.5 Conclusion

The aim of this study was to establish the kinetic, kinematic and temporal parameters of the paddle that differentiate a more successful dragon boat racing crew from a less successful crew. Overall four of the thirteen kinetic, five of the twelve kinematic and two of the seven temporal paddle test parameters were significant and superior for the more successful dragon boat crew. The eleven parameters that differentiated the more successful crew from the less successful were - the time duration of the catch, stroke time, stroke rate; the rate of force development during entry, average drive force, drive force quality (ratio of the average drive force to the maximum paddle force), rate of force reduction at paddle exit; and, forward reach of the paddle, paddle angle at maximum force, paddle angular velocity in water, paddle blade displacement relative to the water surface and stroke length. These results indicate that the more successful dragon boat crew had a more effective paddling technique (greater forward reach at water contact, faster water entry, higher rate of force development, higher angular velocity in water, higher propulsive forces, faster exit, longer stroke length, minimal horizontal blade drag and faster rate of paddling) that produced superior performance during the 30 s maximum effort paddling tests and at dragon boat racing regattas.

CHAPTER 6

Study 3 Comparison of more and less skilled dragon boat paddlers: kinetic and temporal analysis of the paddling stroke

6.0 Purpose of study

In paddle sports high forces and an effective paddling technique are essential for racing success. Dragon boat racing is a young sport with limited information on the kinetics of dragon boat paddling. A pool of knowledge is needed to help coaches and paddlers improve racing performance. The aim of this study is to establish the temporal and kinetic parameters of the paddle that differentiate more skilled paddlers from less skilled paddlers.

6.1 Introduction

In paddle sports boat propulsion is dependent on the forces developed by the paddle as the paddle moves through water. These forces have both magnitude and direction. The magnitude of the forces generated by a paddle is determined by the strength and fitness of the paddler whilst the direction of force application is dependent on the paddler's technique and skill. For racing success high forces and an effective paddling technique are essential in paddle sports (Soper & Hume, 2004; Buckeridge et al, 2015).

One journal article (Ho et al., 2009) and one conference paper (Gomory et al., 2012) are the only sources of information on the kinetics of on-water dragon boat paddling. These two papers were discussed in Chapter 2 as part of the literature review. Comparison of their findings with respect to numerical data was not possible due to differing methods of calculation. Gomory et al., (2012) use the standard numerical format to report their results whereas Ho et al., (2009) used the allometric format. In this study the results are reported in both formats so that direct numerical comparisons with the Ho et al., (2009) data can also be made.

6.2 Methods

Full details of the research strategy and selection of test subjects, test equipment, calibration and synchronisation, test procedures, description of the theoretical model of a dragon boat paddling stroke used to develop the definition of terms, selection of test parameters, data analysis and statistical evaluation, are described in Chapter 3 – Methods. A summary of the methods and specific details of the data analysis and evaluation process applicable to this study are covered in the current chapter.

Volunteer paddlers from three Melbourne dragon boat clubs participated in this study. Informed consent from all participants was obtained prior to testing and the test procedures had prior ethics committee approval. Each participant carried out a 30 s maximum effort paddling test within a boat crew setting at racing pace. A minimum of two minutes rest between each test run was allowed for recovery. Kinetic data was collected sequentially from each test participant at 200 Hz via a custom built strain gauged paddle that was passed on to a new participant at the end of each test run.

For data analysis the participants of this study were grouped on the basis of skill and not on the basis of crew membership as in the Chapter 5 study. Paddlers who had represented their state at the Australian championship or had represented Australia at an international regatta were classified as being more skilled paddlers. All other paddlers were classified as being less skilled. Data from eight more skilled (four male and four female) and fourteen less skilled (seven male and seven female) paddlers was collected for evaluation. There was no significant difference between the more skilled and less skilled group of paddlers with respect to age (53.3 ± 8.7 v. 44.5 ± 15.7 years, $p = 0.054$, $d = 0.67$) and their body mass (70.4 ± 10.5 v. 75.3 ± 14.6 Kg, $p = 0.19$, $d = 0.39$).

Statistical analysis of the results was carried out via an Excel spreadsheet. A single sided unequal variance student t-test at $p<0.05$ was used for significance testing as expectation was known; more skilled paddlers were expected to perform better than the less skilled group of paddlers. Cohen's effect size and 95 % confidence intervals along with standard deviations were calculated and reported for each test parameter.

Results for kinetic test parameters that were common or could be made common with the Ho et al., (2009) study (force rate development, average propulsive force, peak propulsive force, mean to peak force ratio, stroke impulse and stroke impulse rate) were recalculated in the allometric format. The standard results were divided by the body mass of each paddler raised to the power of two-thirds to match the Ho et al., (2009) format. Thus direct numerical comparisons could now be made between all the test groups. Two-tailed unequal variance student t-tests at $p<0.05$ were used for significance testing as there was no expectation as to which group would perform better. The more skilled paddlers of the current study were compared with the Ho elite group and the less skilled paddlers were compared with the Ho sub-elite group of paddlers.

6.3 Results

Ten of the 13 kinetic paddle test parameters were statistically significant with each parameter having a large effect size. More skilled paddlers performed better than the less skilled. All the paddle force parameters except water contact and the negative peak force in air during recovery were significant. The water contact force was almost significant with $p = 0.060$ and $d = 0.79$ indicating that with a different sample of skilled paddlers this parameter could become significant. With respect to impulse parameters all were significant except the impulse during the catch phase of the paddling stroke. In summary the force rate increase on water entry, maximum paddle force, force on the paddle at the vertical position, average catch force, average drive force, force rate reduction to paddle exit, force quality drive, stroke impulse drive, stroke impulse drive rate and stroke impulse recovery were all significant; the catch phase impulse, the paddle water contact force and the peak negative force in air during recovery phase were not significant.

A good way to understand the test parameter results of this study for the key paddle events and the three phases of the paddling stroke is to refer to the theoretical model of dragon boat paddling in Chapter 3 and use figure 3.7-1 reproduced herein to review the test outcomes in context.

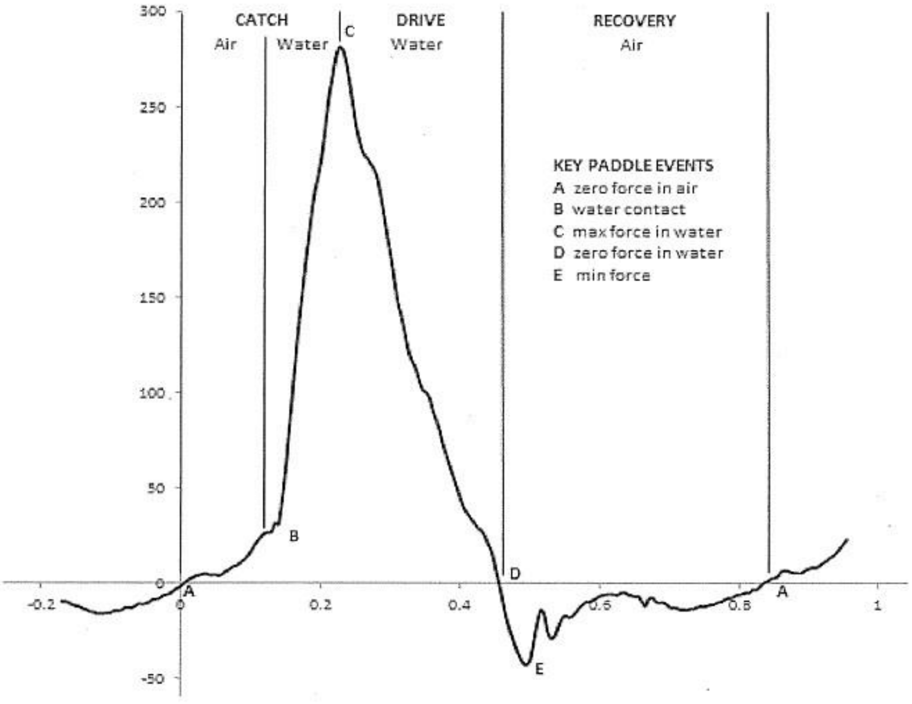

Figure 3.7-1: Key paddle events and phases of a racing paddling stroke.

The average catch force achieved on the paddle (163 v. 117 N, p = 0.018, d = 1.07) is dependent on the area under the force-time curve between the water contact force (42 v. 28N, p = 0.060, d = 0.79) and the maximum force (276 v. 191 N, p = 0.009, d = 1.24). In other words it depends on the impulse produced in the water during the catch phase of the paddling stroke. Now the impulse (area under the force-time curve) depends on the time of application of the paddle force and the average rate of force increase (2540 v. 1337 N/s, p = 0.005, d = 1.63) during water entry. From these facts it can be seen that a particular impulse value can be achieve two ways; a high force and short time or a low force and long time. This is the reason why the average catch and maximum forces were significant for the more skilled paddlers and yet the average catch phase impulse was identical with that of the less skilled group of paddlers (19 v. 19 N.s, p = 0.468, d = 0.03). The more skilled paddlers had reached their higher maximum paddle force in a shorter time than the less skilled paddlers for the catch impulse (area under the curve) to be the equal for both groups. This fact is reflected in the value of the results for the rate of force increase being higher for the more skilled group.

A similar method of reasoning needs to be applied to comprehend the results for the average drive phase force and impulse parameters. The average drive force achieved on the paddle (103 v. 47 N, p = 0.005, d = 1.37) depends on the area under the force-time curve between the maximum force (276 v. 191 N, p = 0.009, d = 1.24) at the end of the catch phase of the paddling stroke and zero force on the paddle at the start of water exit; in other words on the drive phase impulse (43 v. 22 N.s, p = 0.006, d = 1.56). The shape of the curve between these two reference points determines the drive force quality (0.37 v. 0.22, p = 0.006, d = 1.31). In this study the drive force quality, drive phase impulse and the impulse drive rate parameter (49 v. 25 N.s/s, p = 0.003, d = 1.65) were all significant for the more skilled paddlers.

The recovery impulse force (4.3 v. 5.8 N.s, p = 0.028, d = 0.84) was also significant with the more skilled paddlers having a lower value. However the peak negative force in air (-35 v. -38 N, p = 0.281, d = 0.26) during recovery was not significant but the paddle water contact force subsequent to recovery (42 v. 28 N, p = 0.060, d = 0.79) was nearing significance indicating that with a different group of skilled paddlers or larger sample size this parameter could become significant. The kinetic and temporal test parameter results along with 95 percent confidence interval and standard deviations are shown in Table 6.3-1.

Table 6.3-1: Skills level kinetic performance: more skilled versus less skilled paddlers during a 30 s maximum effort paddling test simulating a dragon boat race.

GROUP STATISTICS		More skilled N=8			Less skilled N=14			One tail	Effect Size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Force average catch	N	**163**	31	45	**117**	23	45	**0.018**	**1.07**
Force average drive	N	**103**	30	43	**47**	22	42	**0.005**	**1.37**
Force paddle water contact	N	42	13	19	28	9	17	0.060	0.79
Force paddle maximum	N	**276**	50	72	191	37	71	**0.009**	**1.24**
Force paddle vertical	N	**251**	56	80	180	36	69	**0.029**	**1.01**
Force paddle minimum	N	-35	9	13	-38	8	15	0.281	0.26
Force quality drive	ratio	**0.37**	0.08	0.12	**0.22**	0.06	0.12	**0.006**	**1.31**
Force rate development	N/s	**2540**	685	989	**1337**	327	625	**0.005**	**1.63**
Force rate reduction	N/s	**-575**	215	311	**-260**	113	216	**0.014**	**1.3**
Stroke impulse catch	N.s	19	4	5	19	5	10	0.468	0.03
Stroke impulse drive	N.s	**43**	12	18	22	6	12	**0.006**	**1.56**
Stroke impulse drive rate	N.s/s	**49**	12	18	25	7	14	**0.003**	**1.65**
Stroke impulse recovery	N.s	**4.3**	1	1.4	5.8	1.1	2.1	**0.028**	**0.84**
Stroke rate (reference)	spm	69	3.3	4.3	69	1.7	2.7	0.462	0.047
Stroke time	s	0.869	0.048	0.062	0.871	0.024	0.040	0.462	0.047
Stroke time catch	s	**0.118**	0.23	0.030	0.155	0.015	0.025	**0.004**	**1.45**
Stroke time drive	s	**0.334**	0.051	0.066	0.274	0.014	0.023	**0.014**	**-1.38**
stroke time recovery	s	0.417	0.031	0.040	0.442	0.024	0.040	0.083	0.66
Stroke time propulsive	s	0.452	0.067	0.087	0.429	0.020	0.033	0.234	-0.40
Stroke time propulsive	ratio	0.518	0.052	0.067	0.498	0.022	0.036	0.209	-0.21

Note: Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

Temporal analysis revealed two significant test parameters, the catch (0.118 v. 0.155 s, p = 0.004, d = 1.45) and drive (0.334 v. 0.274 s, p = 0.014, d = -1.38), with better results for the more skilled group of paddlers. The overall propulsive time was longer but not significant for the more skilled group of paddlers. Stroke time (stroke rate), recovery time, propulsive time and propulsion to stroke time ratio were all not significant. However recovery time analysis (0.417 v. 0.442 s, p = 0.083, d = 0.66) produced a low p value and a moderate effect size indicating that with different groups this parameter could become significant.

Comparison of the more skilled paddlers in the current study with the Ho et al., (2009) elite group produced no statistically significant kinetic results. However the propulsive force quality (mean to peak force ratio; 0.41 v. 0.48, p = 0.12, d = 0.89), had a low p value and a large effect size indicating that with a different group of skilled paddlers or larger sample size this parameter could become significant. The force parameters for the Ho et al., (2009) elite group were all slightly higher with the rate of force increase (145 v. 182 N/s.Kg$^{-2/3}$, p = 0.33, d = 0.64), and average propulsive force (6.5 v. 7.9 N/Kg$^{-2/3}$, p = 0.41, d = 0.55) having a moderate effect size. The effect size for peak propulsive force (15.8 v. 16.3 N/Kg$^{-2/3}$, p = 0.87, d = 0.11), was trivial. For the impulse parameters the situation was reversed with the more skilled group having slightly higher values with a small effect size for propulsive stroke impulse (3.5 v. 3.0 N.s/Kg$^{-2/3}$, p = 0.44, d = 0.47) and a trivial effect size for the stroke impulse rate (4.6 v. 4.4 N/Kg$^{-2/3}$, p = 0.81, d = 0.14). Overall the kinetic performance between the two groups was very similar.

The results for the comparison of the more skilled paddlers in the current study with the Ho et al., (2009) elite group along with the 95 percent confidence intervals and standard deviations are shown in Table 6.3-2.

Table 6.3-2: Skills level kinetic performance: more skilled group versus Ho et al (2009) elite group.

GROUP STATITICS		More skilled N=8			Ho elite N=6			Two tail	Effect size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Stroke rate (reference)	spm	**70**	3.1	4.8	**87**	2.2	2.7	**1.1E-06**	**4.58**
Force rate increase	$N/s.Kg^{-2/3}$	145	36	52	182	60	75	0.33	0.64
Peak propulsive force	$N/Kg^{-2/3}$	15.8	2.3	3.4	16.3	4.8	6.0	0.87	0.11
Average propulsive force	$N/Kg^{-2/3}$	6.5	1.54	2.2	7.9	2.8	3.5	0.41	0.55
Mean to peak force ratio	ratio	0.41	0.08	0.11	0.48	0.02	0.03	0.12	0.89
Stroke impulse	$N.s/Kg^{-2/3}$	3.5	0.8	1.1	3	0.9	1.1	0.44	0.47
Stroke impulse rate #	$N/Kg^{-2/3}$	4.6	1.5	2.1	4.4	1.3	1.6	0.81	0.14

- estimated from stroke rate and impulse data of the Ho et al., (2009) study.

Note: Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

Comparison of the less skilled group of the current study with the Ho et al., (2009) sub-elite group produced three statistically significant results for the kinetic paddle parameters. Rate of force increase (75 v. 148 $N/s.Kg^{-2/3}$, $p = 0.01$, $d = 2.18$), average propulsive force (3.3 v. 5.5 $N/Kg^{-2/3}$, $p = 0.03$, $d = 1.2$) and force quality (mean to peak force ratio; 0.3 v. 0.48, p = 8.0E-06, $d = 2.26$), were significantly higher for the Ho et al., (2009) sub-elite group with large effect sizes. These significant differences are likely to be due to a difference in fitness levels between the two groups. The peak propulsive force (10.7 v. 11.4 $N/Kg^{-2/3}$, $p = 0.65$, $d = 0.25$), stroke impulse (2.2 v. 1.9 $N.s/Kg^{-2/3}$, $p = 0.39$, $d = 0.37$) and stroke impulse rate (2.8 v. 2.8 $N/Kg^{-2/3}$, $p = 0.92$, $d = 0.04$) were non-significant with small effect sizes indicating that for these parameters performance for both groups were very similar.

The results for the comparison of the less skilled paddlers in the current study with the Ho et al., (2009) sub-elite group along with the 95 percent confidence intervals and standard deviations are shown in Table 6.3-3.

Table 6.3-3: Skills level kinetic performance: less skilled group versus Ho et al., (2009) sub-elite group.

GROUP STATITICS		Less skilled N=14			Ho sub-elite N=6			Two tail	Effect size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Stroke rate (reference)	spm	**69**	2.1	3.9	**86**	2	2.5	**1.9E-08**	**5.01**
Force rate increase	$N/s.Kg^{-2/3}$	**75**	16	31	**148**	36	45	**0.01**	**2.18**
Peak propulsive force	$N/Kg^{-2/3}$	10.7	1.5	2.9	11.4	2.6	3.2	0.65	0.25
Average propulsive force	$N/Kg^{-2/3}$	**3.3**	1.03	2.0	**5.5**	1.4	1.7	**0.03**	**1.2**
Mean to peak force ratio	ratio	**0.3**	0.05	0.1	**0.48**	0.02	0.03	**8.0E-06**	**2.26**
Stroke impulse	$N.s/Kg^{-2/3}$	2.2	0.5	0.9	1.9	0.4	0.5	0.39	0.37
Stroke impulse rate #	$N/Kg^{-2/3}$	2.8	0.5	1.0	2.8	0.6	0.7	0.92	0.04

- estimated from stroke rate and impulse data of the Ho et al., (2009) study.

Note: Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

6.4 Discussion

No significant parameters were found between the kinetic data of this study for the more skilled group of paddlers and the kinetic data of the elite Ho et al., (2009) group. However the force parameters were all larger for the Ho et al., (2009) elite group. The effect size (0.64) for the rate of force increase was moderate in value and large (0.89) for the mean to peak force ratio which in addition had a small p value (0.12). These results along with the higher stroke rate tend to indicate a difference in paddling technique between these groups and a likely difference in their level of fitness. The three significant kinetic parameters (force rate increase, average propulsive force and mean to peak force ratio) arising from the comparison of the less skilled paddlers of this study with the sub-elite group of paddlers of Ho et al., (2009) does indicate a difference in paddling technique and a difference in fitness level. However, because no boat velocity data was provided by the Ho et al., (2009) study, it is not possible to state which Ho et al., (2009) group, if any, produced superior paddling performance.

Temporal analysis of this study revealed two significant test parameters, catch time and drive time; with better results for the more skilled group of paddlers. Recovery time, stroke time, propulsive time and propulsion to stroke time ratio were not significant. On average the more skilled group of paddlers had a shorter catch time, longer drive time and shorter recovery time than the less skilled paddlers. As a result the overall average stroke time for both groups was almost identical.

Kinetic analysis of the thirteen test parameters produced ten significant results with higher values for the more skilled group of paddlers except for the recovery impulse. These significant parameters were the average catch, drive, maximum and vertical paddle forces, the rate of force development and reduction, drive force quality, drive impulse, drive impulse rate and recovery impulse. Except for the drive phase the performance parameters in general were approximately thirty percent less for the less skilled group of paddlers then for the more skilled. The drive phase performance differed between the groups by approximately fifty percent.

For members of the more skilled group of paddlers the drive impulse and drive force ranged from 24 to 75 N.s and 38 to 175 N with a group average of 43 N.s and 103 N and median values of 35 N.s and 110 N. Similar analysis for members of the less skilled group produced a range from 6 to 42 N.s and 10 to 163 N for the drive impulse and drive force of the crew with a group average of 22 N.s and 47 N and median values of 18 N.s and 32 N.

These substantial differences in results between the two groups were not expected so the data and calculations were checked and rechecked a number of times. However the results were found to be accurate. Hence the results are the natural consequence of the measured raw data.

Three previously unreported kinetic findings arose from this study. One was the forces occurring on the paddle during the air phase of the paddling stroke, two was the substantial force on the paddle at water contact, and three was the point in time and space of maximum paddle force occurrence. The maximum paddle force occurred prior to the vertical paddle position, at the end of the catch phase of the paddling stroke when full blade immersion was achieved and not at the vertical paddle position as claimed by Ho et al., (2009). At water contact the force on the paddle was substantial, approximately 15 percent of the maximum paddle force. The force on the paddle in the air during a paddling stroke ranged from zero at paddle exit to a negative maximum, then back to zero at paddle set up and a substantial positive value at water contact.

The fact that a large paddle force exists at water contact and that the maximum paddle force occurs prior to the vertical paddle position had not been previously reported in the literature. These findings contradict Ho et al., (2009) who stated that paddle entry was defined by the initiation of force on the paddle and that the peak force was reached when the paddle blade was in the vertical position. However Ho et al., (2009) provided no data support their statements. Defining paddle entry by force initiation is an assumption and not an observed fact. Assumptions can lead to errors and using an assumption that in reality is false to synchronise the video and force data produced a temporal error between their kinematic and kinetic data. This error is the likely reason behind Ho et al., (2009) stating that the maximum paddle force occurred at the paddle vertical position.

Other researchers have made similar errors. For instance Brown (2009) in his PhD thesis used paddle entry from high speed video and a 15 N force threshold in the force signal to synchronise kinematic and kinetic data on the basis of advice from the British Canoe Union. The 15N threshold was a better approximation of reality but it was still an assumption that would have produced a temporal error between the kinetic and kinematic data for each of the test subjects.

In this study synchronisation between the 200 Hz force and 200 Hz video data was achieved to an accuracy of 0.005 s by using a light flash that was recorded by the camera and matched during analysis to the trigger signal recorded by the force recording system. This method ensured that the synchronisation process was an objective, observational fact. The difference in findings between this and other studies is probably due to the lack of suitable test equipment in the other studies with which observational objective synchronisation could be achieved.

The use of a strain-gauged paddle in this study enabled paddle forces to be measured continuously during a paddling stroke both in the water and in the air. Boat propulsion is dependent on the paddle forces developed by the paddle whilst the paddle is in the water. However the paddle forces in air provide an important measure of paddling technique and enable key paddle events during the air phase of the paddling stroke to be defined. Since air is much less dense then water, the paddle movement in air encounters little resistance and therefore the small forces due to air resistance may be neglected. Thus the measured paddle forces in air, derived from the flexing of the paddle shaft, can be considered to be due totally to the inertial acceleration of the mass of the paddle blade relative to the paddle shaft, from the point of water exit to the paddle set-up position and then from the set-up position to the surface of the water. This study is the first to examine and report these inertial paddle forces.

A strain-gauged paddle measures the force based on the deflection of its shaft. The magnitude of the force due to deflection is established by calibration. Deflection of the shaft in water is considered to measure positive paddle forces. If the shaft deflects in the opposite direction then it is considered to measure a negative force. The deflection of the shaft in air after the paddle leaves the water is in the opposite direction to that in water. This deflection in air is due to the acceleration of the paddle in the opposite direction to the motion of the paddle in water. As the paddle force in water reduces to zero at the end of the paddling stroke boat propulsion ceases and the paddle leaves the water. This point of zero paddle force in water at the end of the paddling stroke can be defined in force terms as the paddle exit point and it is the point at which the recovery phase of the paddling stroke begins. The paddle force in air becomes negative as the paddle is accelerated forward and up by the paddler. Its magnitude increases and then reduces to zero at the point of maximum paddle height. This point is known as the paddle set-up position and is the point at which the catch phase of the paddling stroke begins. It is the point at which the acceleration of the paddle changes from forward and up to forward and down towards the water. The deflection of the paddle shaft at this point changes from the negative to its positive direction. The magnitude of the positive force increases in line with the increase of the acceleration of the paddle towards the water. At the point of water contact the paddle force is substantial and is approximately 15 percent of the maximum propulsive paddle force. The paddle is pre-loaded as it enters the water and this pre-load contact force is applied to the water during entry.

The fact that the average rate of force increase on water entry and the average rate of force decrease prior to water exit were significant, indicated that the more skilled paddlers employed a faster water entry and a faster water exit in their paddling technique. Similarly the fact that the average force quality (ratio of the average to the maximum force) during the drive phase, the mid part of the paddling stroke, was significant and higher for the more skilled group indicated that the more skilled paddlers were able to maintain a paddle force closer to their maximum during the drive phase of the paddling stroke. Their average drive impulse and average drive impulse rate being significant, verified that the drive phase of the paddling stroke was the dominant and most important propulsive phase of the dragon boat paddling stroke. The fact that the stroke impulse during recovery was lower for the more skilled paddlers and significant, implies the application of smaller forces to the paddle during the air phase of the paddling stroke and thus lower acceleration and smoother action during the recovery phase of the paddling stroke.

In summary the kinetic results of this study indicate that the more skilled paddlers were stronger and fitter than less skilled paddlers. They had a faster paddle entry, achieved and maintained higher paddle forces during the drive phase of the paddling stroke, exited the paddle quicker from the water and had a smoother recovery motion in the air. Their paddling technique was superior and more effective in producing boat propulsion.

The findings of this study may be applicable to other paddle sports such as canoeing (C1, C2 and C4), outrigger and stand-up paddling. As such, replication of this study in these sports would be welcomed along with replication in dragon boating racing using world class paddlers and larger sample sizes.

6.5 Conclusion

The aim of this study was to establish the kinetic and temporal parameters of the paddle that differentiate more skilled paddlers from less skilled paddlers. Two of the seven temporal test parameters for the more skilled group of paddlers were found to be significantly different. Ten out of the thirteen kinetic paddle parameters were also found to be significantly different. These twelve parameters that significantly differentiated more skilled paddlers from the less skilled were the catch time and drive time, the rate of force development on water entry, maximum paddle force, force on the paddle at the vertical position, average catch force, average drive force, force rate reduction to paddle exit, force quality drive, stroke impulse drive, stroke impulse drive rate and stroke impulse recovery. The results of this study indicate that the more skilled paddlers had a more effective paddling technique (faster water entry, higher more constant drive forces, quicker exit and smoother recovery) than the less skilled paddlers and produced superior performance during the simulated dragon boat races.

CHAPTER 7

Study 4 Comparison of more and less skilled dragon boat paddlers: kinematic analysis of the paddling stroke

7.0 Purpose of study

A common problem faced by coaches of dragon boat racing teams is the assessment of paddling technique and paddling skill of their paddlers. Currently this is done qualitatively via visual observations and video analysis. An objective method is needed to supplement such qualitative assessments. By measuring the paddle kinematics of paddlers having different skill levels the characteristics that differentiate more skilled paddlers from less skilled paddlers may be identified. Hence the aim of this study is to establish the kinematic parameters of the paddle that differentiate more skilled paddlers from less skilled paddlers.

7.1 Introduction

Coaches of dragon boat racing teams need to assess the paddling technique and paddling skill of their paddlers for team selection. Currently in paddle sports such as canoeing, kayaking and rowing, technique and skill are assessed via field based visual or video recorded observations focussed on the movements of the paddle and the paddler (Soper, & Hume, 2004; McDonnell et al., 2012). Technical templates are available to assist coaches for canoeing (Buday, 2009) and kayaking (Oldershaw, 2009). In dragon boat racing these methods are also used to assess paddling technique and paddling skill. However these qualitative methods are subjective in nature and are dependent on the experience and opinions of coaches. An objective method is needed to supplement such qualitative assessments.

To comprehend what makes a paddling stroke skilful an understanding of the movements of the paddle in water is required. By studying the paddle kinematics of paddlers having different skill levels the characteristics that differentiate more skilled paddlers from less skilled paddlers may be identified. Thus this study is focussed on the kinematics of the dragon boat paddle during a paddling stroke performed at racing pace in a simulated race.

7.2 Methods

Full details of the research strategy and selection of test subjects, test equipment, calibration and synchronisation, test procedures, description of the theoretical model of a dragon boat paddling stroke used to develop the definition of terms, selection of test parameters, data analysis and statistical evaluation, are described in Chapter 3 – Methods. A summary of the methods and specific details of the data analysis and evaluation process applicable to this study are covered in the current chapter.

Volunteer paddlers from three Melbourne dragon boat clubs participated in this study. Informed consent from all participants was obtained prior to testing and the test procedures had prior ethics committee approval. Each participant carried out a 30 s maximum effort paddling test within a boat crew setting at racing pace. A minimum of two minutes rest between each test run was allowed for recovery. Kinematic data was collected sequentially from each test participant for one paddling stroke via a stationary video camera (Sony HDR-HC7) operating at 200 Hz.

For data analysis the participants were grouped on the basis of skill. Paddlers who had represented their state at the Australian championship or had represented Australia at an international regatta were classified as being more skilled. All other paddlers were classified as being less skilled. Data from eight more skilled (four male and four female) and fourteen less skilled (seven male and seven female) paddlers was collected for evaluation. There was no significant difference between the more skilled and less skilled group of paddlers with respect to age (53.3 ± 8.7 v. 44.5 ± 15.7 years, $p = 0.054$, $d = 0.67$) and body mass (70.4 ± 10.5 v. 75.3 ± 14.6 Kg, $p = 0.19$, $d = 0.39$).

Statistical analysis of the results was carried out via an Excel spreadsheet. A single sided unequal variance student t-test at $p < 0.05$ was used for significance testing as expectation of performance was known; more skilled paddlers were expected to perform better than the less skilled group of paddlers with respect to the operationalised test parameters defining a good dragon boat paddling stroke. Cohen's effect size and 95 % confidence intervals along with standard deviations were calculated and reported for each test parameter.

The comparison of more skilled paddlers against less skilled paddlers for the videoed paddling stroke was made using twelve kinematic test parameters. These comprised boat crew related kinematic, kinetic related kinematic and paddling technique related kinematic variables. Average boat velocity, boat velocity during propulsion and boat displacement per paddling stroke comprised the boat crew related test parameters. Paddle angles at water contact, maximum force, water exit, zero force in air and zero force in water were the kinetic related kinematic test parameters. Test parameters measuring aspect of paddling technique were paddle blade displacement at water contact (forward reach of the paddle), horizontal paddle blade displacement in water (movement of the paddle on the surface of the water during the water phase of the paddling stroke), average angular velocity of the paddle in water and the paddle stroke length.

Results for the kinematic parameters used by Ho et al (2009) were also calculated from the study data and statistically compared with their findings. As there were no expectations with respect to performance two-tailed Student t-tests at $p < 0.05$ were used for significance testing. More skilled paddlers of the current study were matched against the Ho elite group whilst the less skilled paddlers were matched with the Ho sub-elite group of paddlers. Comparisons were made for the common test parameters; stroke rate, water phase to stroke time ratio, paddle angle at water contact, paddle angle at water exit and stroke length.

7.3 Results

Figure 3.7-1 from Chapter 3 reproduced herein illustrates the force-time aspects of the three action phases and the key events of the dragon boat paddling stroke. The results of this study need to be viewed in context with respect to the theoretical model of the dragon boat paddling stroke.

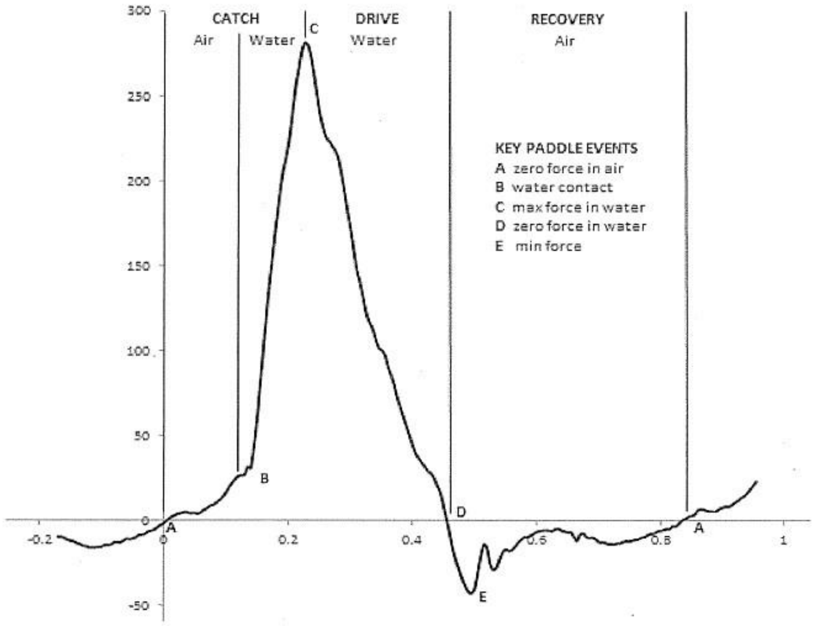

Figure 3.7-1: Key paddle events and phases of a racing paddling stroke.

Of the twelve kinematic test parameters five were statistically significant and superior for the more skilled group of paddlers. Four of these significant test parameters were paddle related and the other was the boat velocity during paddle propulsion. The four paddle related parameters were paddle blade forward reach at water contact, horizontal blade displacement on the water surface, paddle angular velocity in water and paddle angle at water exit.

In terms of crew related test parameters (average boat velocity, boat velocity during propulsion and boat displacement per paddling stroke) only one, the boat velocity during propulsion, was statistically significant (3.99 v. 3.71 m/s, p = 0.018, d = 0.97). However the average boat velocity (3.74 v. 3.56 m/s, p = 0.055, d = 0.73) was close to being significant and had a large effect size indicating that with a different group of skilled paddlers or larger sample size this parameter could have become significant. Boat displacement per stroke (3.23 v. 3.11 m/s, p = 0.127, d = 0.49) was higher for the more skilled group with a relatively low p value and an almost moderate effect size.

Of the kinetic related kinematic test parameters (average paddle angles at water contact, maximum force, water exit, zero force in air and zero force in water) only the average paddle angle at water exit was statistically significant (-59 v. -52 degrees, p = 0.014, d = 1.12). All other results for this group of parameters were not statistically significant. However the effect size for the average paddle angle at zero force in water (-55 v. -47 degrees, p = 0.397, d = 1.05) was large. The average paddle angles at water contact were 33 versus 34 degrees, at maximum force 7.5 versus 5.7 degrees and at zero force in air 26 versus 24 degrees for the more skilled and less skilled paddlers respectively.

The test parameters measuring paddling technique, (paddle blade forward reach at water contact, average angular velocity of the paddle in water, horizontal paddle blade displacement on the water surface and the paddle stroke length), produced three statistically significant results; all but stroke length were statistically significant. Paddle stroke length was not significant (1.68 v. 1.37 m, p = 0.291, d =1.54) but the effect size was large. The average paddle blade forward reach at water contact (1.34 v. 1.26 m, p = 0.044, d =0.75) was significant with a high moderate effect size. The average angular velocity of the paddle in water (48 v. 44 deg/s, p = 0.019, d =1.11) was significant with a large effect size. And the average horizontal paddle blade displacement on the water surface (0.05 v. 0.27 m, p = 0.3.4E-05, d =2.01) was significant with a very large effect size. Together these three paddle kinematic test parameters provide an objective measure of paddling technique and skill.

More detailed information is provided in Table 7.3-1, with the 95 percent confidence intervals and the standard deviations shown for each test parameter. The table also notes the removal of an outlier from the data set of the more skilled paddlers for the horizontal blade displacement parameter. This removal was done after a scatter plot inspection revealed the problem. The inclusion of this outlier would have distorted the average value of the test parameter sufficiently to have concealed an important finding. Values with p < 0.05 and d > 0.8 are shown in bold font.

Table 7.3-1: Skills level kinematic performance: more skilled paddlers versus less skilled paddlers during a 30 s maximum effort paddling test simulating a dragon boat race.

GROUP STATISTICS		More skilled N=8			Less skilled N=14			One tail	Effect size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Blade forward reach	m	**1.34**	0.05	0.08	**1.26**	0.07	0.13	**0.044**	0.75
Blade displacement surface[1]	m	**0.12**	0.03	0.14	**0.27**	0.07	0.14	**0.017**	**1.12**
Boat displacement per stroke	m	3.23	0.12	0.19	3.11	0.16	0.29	0.127	0.49
Boat velocity average	m/s	3.74	0.14	0.22	3.56	0.15	0.28	0.055	0.73
Boat velocity propulsion	m/s	**3.99**	0.17	0.26	**3.71**	0.18	0.33	**0.018**	**0.97**
Paddle angle water contact	deg	33	2.9	4.4	34	2.6	4.8	0.410	0.1
Paddle angle max force	deg	7.5	3.5	5.1	5.7	2.5	4	0.151	0.43
Paddle angle zero force water	deg	-55	5	8	-47	4.5	8.3	0.397	**1.05**
Paddle angle water exit	deg	**-59**	2.8	4.2	**-52**	4.1	7.5	**0.007**	**1.12**
Paddle angle zero force air	deg	26	3.7	5.7	24	6.7	12	0.139	0.3
Paddle angular velocity water	deg/s	**48**	2.8	4.3	**44**	1.7	3.1	**0.019**	**1.11**
Paddle stroke length	m	1.68	0.14	0.2	1.37	0.11	0.21	0.291	1.54
Stroke rate (reference)	spm	70	3.1	4.8	69	2.1	3.9	0.412	0.11

Note – an outlier >0.6 m was removed from the more skilled group data set

The justification for the removal of the outlier rests on a limitation of the definition for a more skilled paddler. More skilled paddlers were defined as being a member of a state team at the Australian championships or a member of the Australian team at an international event; in other words being a member of a high performance boat crew. However it is possible to achieve high level performance at championships through low skill and very high levels of power. It is believed that this was the case in this situation. The paddler whose value was removed from the data set was a member of the less successful crew in the Chapter 5 study but was classified as a more skilled paddler on the basis of his experience and performance. However he produced the highest horizontal blade displacement of all participants as shown in Figure 7.3-1.

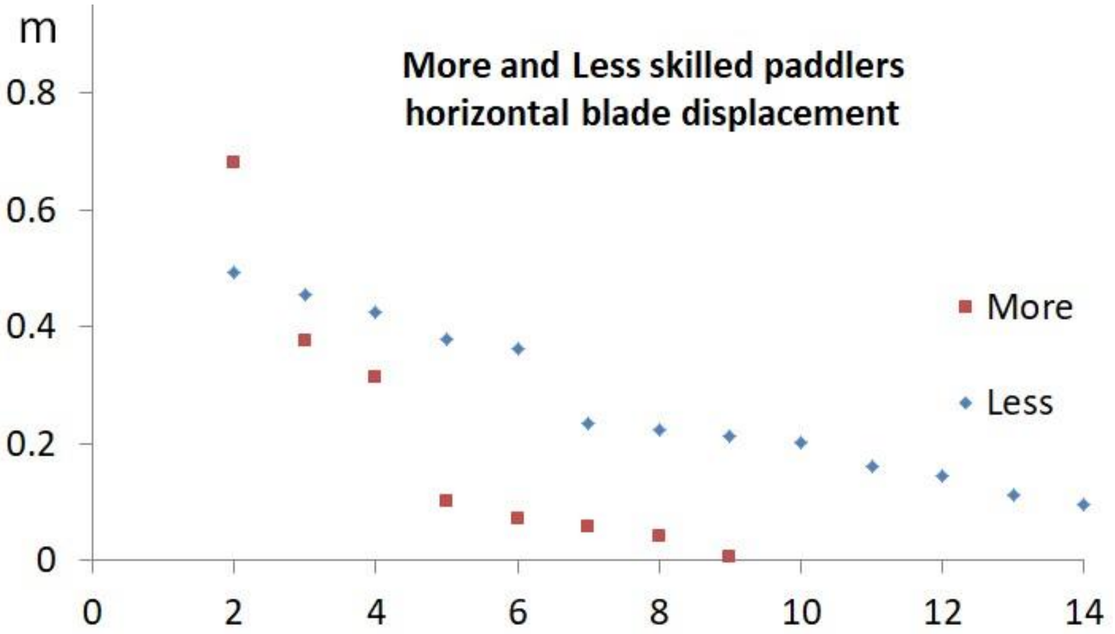

Figure 7.3-1 Scatter plot: Horizontal paddle blade displacement for all participants.

Comparison of more skilled paddlers in the current study with the Ho et al., (2009) elite group for kinematic parameters that were common between the two studies (stroke rate, water phase to stroke time ratio, paddle angle at water contact, paddle angle at water exit and stroke length) revealed two significant differences; stroke rate (70 v. 87 spm, p = 1.1E-06, d = 4.58) and the stroke length (1.68 v. 1.3 m, p =8.3E-04, d = 2.27). Result for all other test parameters between the two groups were not significant; average water phase to stroke time ratio (0.58 v. 0.56, p = 0.703, d = 0.11), paddle angle at water contact (33 v. 40 deg, p = 0.127, d = 1.14), and paddle angle at water exit (-59 v. -63 deg, p = 0.158, d = 0.9), However the average paddle angle at water contact and paddle angle at water exit both had relatively low p values and large effect sizes indicating that with a different group of skilled paddlers these parameters could become significant. The 95 percent confidence intervals and the standard deviations for each test parameter are shown in Table 7.3-2. Values with p < 0.05 and d > 0.8 are shown in bold font.

Table 7.3-2: Skills level kinematic performance: more skilled group versus Ho et al., (2009) elite.

GROUP STATITICS		More skilled N=8			Ho elite N=6			Two tail	Effect size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Stroke rate	spm	**70**	3.1	4.8	**87**	2.2	2.7	**1.1E-06**	**4.58**
Water phase to stroke time	ratio	0.58	0.13	0.18	0.56	0.02	0.02	0.703	0.18
Paddle angle water contact	deg	**33**	2.9	4.4	**40**	7	8.7	0.127	**1.14**
Paddle angle water exit	deg	**-59**	2.7	4.2	**-63**	4	5	0.158	**0.9**
Paddle stroke length	m	**1.68**	0.14	0.2	**1.3**	0.1	0.1	**8.3E-04**	**2.27**

The comparison of the less skilled group of the current study with the Ho et al., (2009) sub-elite group produced a higher number of significant differences between the groups than did the comparisons of the more skilled groups. Three out of the five test parameters produced significant differences with large effect sizes; stroke rate (69 v. 86spm, p = 1.9E-08, d = 5.01), paddle angle at water exit (-52 v. -63 deg, p = 2.4E-03, d =1.63) and paddle stroke length (1.37 v. 1.2 m, p = 0.041, d = 0.97). The paddle angle water contact (33 v. 39 deg, p =

0.055, d = 1.17), had a large effect size and was almost significant at the standard p = 0.05 level. Thus with a different group of skilled paddlers paddle angle at water contact is likely to become significant. However the stroke time ratio (0.56 v. 0.51, p = 0.157, d = 0.55) was not significant but it did have a relatively low p value and a moderate effect size. The 95 percent confidence intervals and the standard deviations for each test parameter are shown in Table 7.3-3. Values with $p < 0.05$ and $d > 0.8$ are shown in bold font.

Table 7.3-3: Skills level kinematic performance: less skilled group v. Ho et al., (2009) sub-elite.

GROUP STATISTICS		Less skilled N=14			Ho sub-elite N=6			Two tail	Effect size
Test parameters	**Units**	**Ave**	**CI**	**SD**	**Ave**	**CI**	**SD**	**p value**	**Cohen's d**
Stroke rate	spm	69	2.1	1.9	**86**	2	2.3	**1.9E-08**	**5.01**
Water phase to stroke time	ratio	0.56	0.06	0.11	0.51	0.02	0.02	0.157	0.55
Paddle angle water contact	deg	**34**	2.6	4.8	**39**	4	5	0.055	**1.17**
Paddle angle water exit	deg	**-52**	4.1	7.5	**-63**	4	5	**2.7E-03**	**1.63**
Paddle stroke length	m	**1.37**	0.11	0.21	**1.2**	0.1	0.1	**0.041**	**0.97**

7.4 Discussion

The probable explanation as to why the average boat velocity during propulsion was statistically significant and the average boat velocity was not, lies in the data collection process. Data has to be collected in a crew setting; dragon boat paddlers cannot be tested on their own. Data for the less skilled group came from both crews. Ten came from the less successful boat crew and four came from the more successful crew. The four results that came from the more successful crew had higher average boat velocities which brought up the average of the less skilled group to the point where the difference between the groups was not significant.

During a dragon boat race the stroke rate, average boat velocity, boat velocity during propulsion and boat displacement per paddling stroke are determined by the combined effort of the boat crew. The outcomes for these test parameters are not a measure of individual paddler performance. However these measures of boat crew performance need to be known as they provided a contextual background under which the results for individual performance measures were collected. For the individual test parameter results to be valid the boat crew related parameters under which collection occurred need to be representative of actual racing conditions.

From Australian state and national championships it is known that winning times for 200 m races for Masters Category dragon boat crews (paddlers aged 40 years and over) generally lies in the range of 50 to 60 seconds resulting in an average boat velocity ranging between 3.3 to 4.0 m/s. The average boat velocity of 3.56 and 3.74 m/s for the two groups in this study fall into this range and are therefore representative of actual racing conditions. Hence the individual kinematic performance results for the kinetic and technique related test parameters are valid and reliable.

For the Ho et al., (2009) study there is no result for boat crew determined test parameters apart from stroke rate. Therefore we cannot be as confident as for the current study that the individual performance results were collected under representative racing conditions. However in order to make a comparison with the current study we need to assume that the Ho et al., (2009) data is representative of racing conditions.

In comparing the more skilled paddlers of the current study with the Ho elite group two test parameters were highly significant: stroke rate (70 v. 87 spm, p = 1.1E-06, d = 4.58) and stroke length (1.68 v. 1.3 m, p =8.3E-04, d = 2.27) indicating a difference in paddling technique between the groups. Without knowing the results for boat crew determined test parameters for the Ho et al., (2009) study we cannot determine which paddling technique produces superior racing performance. Results for the water phase to paddling stroke time ratio, paddle angle at water contact and paddle angle at water exit were similar, thus mitigating the differences in paddling technique and perhaps indicating that there may be a trade-off between stroke rate and stroke length for similar boat performance.

The results for the comparison of the Ho et al., (2009) sub-elite group with the less skilled group of the current study differed more substantially. The difference in stroke rate (69 v. 86 spm, p = 1.9E-08, d = 5.01) and stroke length (1.37 v. 1.2 m, p = 0.041, d = 0.97) was again significant but so was the paddle angle at water exit (-52 v. -63 deg, p = 2.4E-03, d = 1.63). The paddle angle at water contact (33 v. 39 deg, p = 0.055, d =1.17) was almost significant. These results appear to indicate that there were more substantial differences in paddling technique between the sub-elite and less skilled group of paddlers than between the elite and the more skilled group.

Whilst the comparison of the current study with the Ho et al., (2009) data produced useful results the most useful findings came from the comparison of the more skilled group of the current study with the less skilled group. The average boat velocity during testing for the current study lay within the range observed at state and national championships for paddlers of similar age thus the findings can be regarded as being representative of racing conditions. For the crew related test parameters (stroke rate, average boat velocity, boat velocity during propulsion and boat displacement per paddling stroke) only the boat velocity during propulsion was significant (3.99 v. 3.71 m/s, p = 0.018, d = 0.97). Similarly for the kinetic related kinematic test parameters only the average paddle angle at water exit was statistically significant (-59 v. -52 degrees, p = 0.014, d = 1.12). Results for all other kinetic related test parameters (average paddle angles at water contact, maximum force, zero force in air and zero force in water) were not statistically significant. These results tend to indicate a difference in technique at the exit point of the paddling stroke and a longer stroke length for the more skilled group. The average stroke length was in fact longer for the more skilled group (1.68 ± 0.20 versus 1.37 ± 0.21 m) but was not statistically significant due to the standard deviations of the two distributions overlapping each other.

Test parameters measuring paddling technique produced the most important findings. Three paddle kinematic test parameters were statistically significant; the average paddle blade forward reach at water contact (1.34 v. 1.26 m, p = 0.044, d = 0.75), the average angular velocity of the paddle in water (48 v. 44 deg/s, p = 0.019, d = 1.11) and the average horizontal paddle blade displacement on the water surface (0.05 v. 0.27 m, p = 0.3.4E-05, d = 2.01). The average horizontal paddle blade displacement on the water surface (horizontal movement of the paddle relative to the surface of the water between the water contact point and water exit point of the paddle blade) were in the direction of boat movement indicating that a drag force, reducing boat speed, was being applied by a segment of the paddle blade as a consequence of its rotation in the water during the paddling stroke. Less skilled paddlers produced a slower average angular velocity of the paddle and therefore a greater horizontal displacement of the paddle blade as a result, due to its upper segment being dragged along by the boat for a longer period of time.

The expected direction of paddle movement in the water was towards the back of the boat as per commonly held view of paddlers and coaches that the boat is moved forward by pushing water backwards. This common belief is false and is probably based on observations of the initial paddling stroke that commences boat movement. In the first stroke the paddle blade does move horizontally backwards in the water as the boat moves forward but not because water is moved backwards but because the boat is pushed forward by the levering action of the paddle blade. The water in fact moves from the rear face of the paddle blade to its edges around to the front face of the blade creating a vortex tube and it is this vortex tube that is responsible for producing boat propulsion (Jackson et al 1992; Kim, 2010; Kim and Morteza, 2011).

The magnitude of the horizontal paddle blade displacement on the surface of the water is determined by the forward boat speed and the rearward angular rotation of the paddle during the paddling stroke. The retarding force acting on the boat is determined by the forward rotation of the paddle blade relative to its instantaneous centre of rotation with respect to the water surface. The greater the horizontal paddle blade displacement the deeper is the location of the instantaneous centre of rotation of the paddle blade. The deeper the location of the centre of rotation of the paddle blade the greater the surface area of the paddle blade rotating in the forward direction producing a greater retarding force acting on the boat.

From the above it can be seen that boat velocity, angular velocity of the paddle and horizontal paddle blade displacement are interconnected. To produce a horizontal paddle blade displacement at the surface of the water, the instantaneous centre of rotation of the paddle blade must be under the water surface. The lower the centre of rotation beneath the water surface the greater the horizontal displacement and the greater the retarding force. To reduce the retarding force to zero the horizontal paddle blade displacement must also be reduced to zero. For this to occur, the instantaneous centre of rotation of the paddle blade must move to the water surface. This can be achieved by matching the angular velocity of the paddle during propulsion (the water phase of a paddling stroke) to the horizontal speed of the boat.

Therefore it can be deduced that horizontal paddle blade displacement in water during the paddling stroke can be used to evaluate the paddling technique and the level of paddling skill for a paddler. The smaller the value of the horizontal paddle blade displacement in water for a paddler the better the paddling technique and the higher the level of paddling skill. When the horizontal paddle blade displacement is zero it could be said that ideal paddling technique and optimum paddling skill is achieved. Hence a new definition and measure of skill is proposed from the results of this study, namely that the horizontal paddle blade displacement on the surface of the water and the average angular velocity of the paddle blade during propulsion be used as objective empirical measures of paddling technique and paddling skill.

Plagenhoef (1979) after studying Olympic and world champion canoe and kayak paddlers for more than nine years via high speed film recordings came to a similar conclusion. He concluded that the motion of the paddle blade in water is sufficient on its own to differentiate good paddlers from poor paddlers – no other information was needed. He also stated that for an efficient paddling stroke the 'blade is actually stationary in the water' (Plagenhoef, 1979, p456). It seems that the Plagenhoef (1979) findings were not picked up and disseminated, perhaps because of the introduction of the winged paddle in kayaking (Kendal & Sanders, 1992) that changed kayak paddling technique. However Plagenhoef's findings are still applicable today to canoeing and all other drag based paddle sports.

7.5 Conclusion

The aim of this study was to establish the kinematic parameters of the paddle that differentiated more skilled paddlers from less skilled paddlers. Four paddle kinematic parameters were found to be significant. Paddle blade forward reach at water contact during the catch phase of the paddling stroke. Angular velocity of the paddle during propulsion, that is during the time that the paddle is in the water. The horizontal blade displacement produced on the water surface; the distance between the water contact point at paddle entry and the water exit point of the paddle. And the paddle angle at water exit. These four significant kinematic parameters of the paddle differentiated more skilled paddlers from the less skilled. Two of these kinematic paddle parameters provide key measures of paddling technique, skill and propulsion; the average angular velocity of the paddle in water and the average horizontal paddle blade displacement at the water surface. It is recommended that these two parameters be used as an objective measure of paddling skill and paddling technique.

CHAPTER 8

Overview of the thesis and future research

8.1 Overview of the thesis

The general aim of this thesis was to examine the biomechanics of dragon boat paddling at the fundamental level of the paddle; the tool by which boat propulsion is produced. A theoretical model of the dragon boat paddling stroke was developed on engineering principles for the purpose of analysis. This model was based on the force-time curve of the paddling stroke, action phases of the stroke and key paddle events. The action phases of a paddling stroke are the catch, drive and recovery. The key paddle events of a paddling stroke are set-up, water contact, full immersion, vertical position, exit, and, occurrence times for maximum, minimum and zero forces in water and air.

The action phases and key events were mapped on the force time curve for comprehension and analysis. Kinetic, kinematic and temporal test parameters were developed for the paddle from the model. The temporal test parameters were stroke time, stroke rate, catch, drive and recovery time, propulsive time and propulsive stroke time ratio. Kinematic test parameters were position and angles at key paddle events, and velocities during the action phases of the paddling stroke. Kinetic test parameters were force values at key paddle events and impulse during the three action phases of the paddling stroke. Parameters for statistical evaluation were selected on the basis of previous research and the paddling experience of the author.

Kinetic, kinematic and temporal data for the paddle were obtained from on-water testing of two dragon boat crews at racing pace during 30s maximum effort paddling tests. The two crews differed in terms of racing success; one was more successful than the other. Each crew consisted of paddlers having different levels of skill. Paddlers were divided into two categories of skill. Those who had represented their state at Australian championships or had represented Australia at international championships were classified as more skilled. All other paddlers were classified as being less skilled. The majority of the crew in the more successful boat crew were more skilled paddlers whilst the majority of the less successful boat crew consisted of less skilled paddlers.

Statistical evaluation of the results of the on-water tests for the paddle kinetic, kinematic and temporal parameters was carried out two ways; via crew membership and skill level. For the crew level analysis the test groups were based on crew membership. For the skill level analysis the test groups were based on skill levels. Both methods contained the risk of confounded findings. Each crew group contained members from both levels of skill and each skill group consisted of members from both crews. However this problem cannot be avoided as dragon boat racing is a team sport and paddlers need to be tested in a crew setting under representative racing conditions. Hence careful thought is required to interpret the results.

Four studies were carried out for the thesis. The first study investigated the qualitative coaching model used to teach paddlers a good dragon boat paddling stroke. This model states that a good dragon boat paddling stroke has *a high set-up, maximum reach, an aggressive catch, a powerful drive, a quick exit and a smooth recovery*. However the model has not been tested and there is no biomechanical evidence to support it. Thus the aim of this study was to fill this knowledge gap. The qualitative concepts of the model were operationalised by assigning quantitative measurable test parameters against each qualitative concept. These operationalised test parameters were chosen from the paddle parameters of the theoretical model of dragon boat paddling. Results from the on-water tests for the chosen test parameters were statistically analysed at the skill level for the two groups of paddlers to assess the level of support for the coaching model. Seven out of the nine parameters were significant and gave strong support for the coaching model. The qualitative concept of *a high set-up* was not supported by its operationalised test parameter hence it was removed from the model. The coaching model was revised to *maximum reach, an aggressive catch, a powerful drive, a quick exit and a smooth recovery* and recommended to be used for teaching paddlers a good dragon boat paddling stroke.

The second study examined the kinetic, kinematic and temporal test parameters of the paddle that differentiated a more successful dragon boat racing crew from a less successful racing crew. The results from the on-water tests were statistically analysed on the basis of crew membership. Four kinetic, five kinematic and two temporal paddle parameters were significant. The temporal parameters were the catch and stroke time of the paddling stroke. Kinematic paddle parameters were paddle reach at water contact, paddle angle at maximum force, paddle angular velocity in water, horizontal paddle displacement on the water surface and paddle stroke length. Kinetic paddle parameters were the rate of force development during water entry, the average force during the drive phase of the paddling stroke, the drive force quality (ratio of the average drive force to the maximum paddle force) and the rate of force reduction at paddle exit.

In the third study the kinetic and temporal test parameters of the paddle that differentiated more skilled paddlers from less skilled were investigated. The results from the on-water tests were statistically analysed on the basis of skill. Ten kinetic and two temporal paddle parameters were statistically significant. The temporal parameters were the catch and drive time and the kinetic parameters were the rate of force development during water entry, maximum paddle force, force on the paddle at the vertical position, average catch force, average drive force, force rate reduction leading to paddle exit, force quality drive, stroke impulse drive, stroke impulse drive rate and stroke impulse recovery.

For the fourth and final study, the kinematic test parameters of the paddle that differentiated more skilled paddlers from the less skilled were examined. The results from the on-water tests were statistically analysed on the basis of skill. Four kinematic paddle parameters were statistically significant; paddle blade forward reach at water contact, angular velocity of the paddle during propulsion, horizontal blade displacement on the water surface and the paddle angle at water exit.

Overall the following observation can be made. The five significant kinematic paddle parameters in study two and the ten kinetic significant paddle parameters in study three fully define the skill dimensions of the dragon paddling stroke. The four significant kinetic paddle parameters in study two are a subset of the ten significant kinetic paddle parameters in study three. Three of the four significant kinematic paddle parameters in study four are a subset of the five significant kinematic paddle parameters in study two. Of these significant paddle parameters the common kinetic and kinematic parameters between the studies are the most important (rate of force development, average drive force, drive force quality and rate of force reduction; forward reach at water contact, angular paddle velocity and horizontal blade displacement).

8.2 Future research

The average boat velocities during the tests for this thesis were in the 3.5 – 4.0 m/s range. In world championship events average boat velocities are usually in the range of 4.5 – 5.0 m/s. Useful information could be gained if the studies in this thesis were replicated with higher skilled paddlers at world championship level.

National teams worldwide train as a team in dragon boats but they also train as individuals in single craft such as OC1 canoes or as here in Australia in modified TK1 kayaks. An outrigger is added to a TK1 for stability and a standard dragon boat paddle is used for paddling. The studies from this thesis and those proposed above could all be repeated with paddlers using the modified TK1 kayaks. Selection at the national level is to a substantial extent based on single craft time trials so this research would be valuable.

The forces generated by the paddle-water interaction are transferred via the body of the paddler to the seat and foot rest of the dragon boat or the modified TK1. These seat and foot forces could be measured by developing appropriate force transducers. Research by Brown (2009) has shown that foot forces in kayaking are important in transferring the propulsive force from the paddle to the kayak. It is likely that this would apply for dragon boats and single crafts.

To have a complete understanding of paddle propulsion the hydrodynamics of paddle-water interaction would need to be studied. Literature on the hydrodynamics of paddle propulsion is very limited. To the author’s knowledge there are only two research papers (Jackson, Locke & Brown, 1992; Kim & Morteza, 2011) and a PhD thesis (Kim, D 2010) available on the topic of paddle propulsion. Jackson et al (1992) examined paddle propulsion from first principles using an analytical method and reported force data obtained through the use of a towing-tank apparatus that measured blade forces and velocity simultaneously as a function of time. Kim (2010) for his PhD studied three-dimensional vortex formation and the propulsive performance of flapping locomotion experimentally using a simplified mechanical model, a water tank and three-dimensional flow field measurement (defocusing digital particle image velocimetry). His findings were published as a paper on drag-based paddling propulsion (Kim & Morteza, 2011).

It should be possible to construct a paddling tank with a mechanism that reproduces the dragon boat paddling stroke with respect to paddle kinetics and kinematics in a laboratory setting. Then paddling technique could be studied by the above method of three-dimensional flow field measurement. Digital particle image velocimetry equipment may be required along with a supervisor with fluid mechanics expertise. It would be a multi-disciplinary project that would result in deep knowledge of paddle hydrodynamics and paddle propulsion.

CHAPTER 9

Conclusions of the thesis

The general aims of this thesis were to gain an understanding of the biomechanics of dragon boat paddling from the perspective of the paddle. This was achieved by analysing the temporal, kinetic and kinematic parameters of the paddle for more skilled and less skilled paddlers. The paddle parameters were measured in a crew setting during maximum effort paddling tests that simulated dragon boat races. Two dragon boat crews were used; one having a more successful race record than the other.

In study one the specific aim was to operationalise the qualitative concepts of the coaching model of a good dragon boat paddling stroke so that its biomechanical support could be evaluated. Seven of its operationalised paddle parameters (paddle reach at water contact, force rate increase, maximum paddle force, drive impulse, drive impulse rate, force rate reduction and recovery impulse) were statistically significant giving good support to the coaching model – *maximum reach, an aggressive catch, a powerful drive, quick exit and a smooth recovery*.

The aim of study two was to establish the kinetic, kinematic and temporal parameters of the paddle that differentiated a more successful dragon boat racing crew from a less successful crew. Two temporal and five paddle kinematic parameters were significant (catch and stroke time, paddle reach at water contact, paddle angle at maximum force, paddle angular velocity in water, paddle blade displacement on the water surface and stroke length). Four kinetic paddle parameters were significant (rate of force development during water entry, average drive force, the drive force quality and the rate of force reduction at paddle exit). Together these eleven paddle parameters differentiated a more successful dragon boat racing crew from a less successful crew.

In study three the aim was to establish the kinetic and temporal parameters of the paddle that differentiated more skilled paddlers from less skilled paddlers. Two temporal and ten kinetic paddle parameters were significant (catch and drive time, rate of force development, maximum paddle force, force at paddle vertical position, average catch force, average drive force, force rate reduction at paddle exit, force quality drive, stroke impulse drive, stroke impulse drive rate and stroke impulse recovery). These twelve paddle parameters differentiated more skilled paddlers from less skilled paddlers on the basis of skill.

The aim of study four was to establish the kinematic parameters of the paddle that differentiated more skilled paddlers from less skilled paddlers. Four paddle kinematic parameters were significant (paddle reach at water contact, paddle angular velocity in water, horizontal blade displacement on the water surface and paddle angle at water exit). These four significant kinematic parameters of the paddle differentiated more skilled paddlers from the less skilled on the basis of skill.

Together these four studies provide a biomechanical foundation for the sport of dragon boat racing. Coaches and paddlers can use the findings of the thesis to improve paddling technique, paddling skill and racing performance.

APPENDIX

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